from MYTH to REASON

WOODBRIDGE RILEY

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THE STORY OF THE MARCH OF MIND IN THE INTERPRETATION OF NATURE

BY

WOODBRIDGE RILEY

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ILLUSTRATED

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PREFACE

One of the great tasks of man has been the interpretation of nature. He ever feels compelled to explore his habitation, whether it be a hut, a house, or a palace. He may no longer remember his remote birthplace, but we now have means to recover the early records of the past. In the infancy of the race the known earth appeared to man little more than a tent of dropping clouds; there were the Middle Ages when his house was a haunted house, full of dire portents and foreboding figures. But when during the Renaissance, "lands, seas and stars were immensely enlarged," the individual came to believe himself a dweller in a veritable palace, where all the materials were precious, and where he was bounded only by the glittering sky beyond.

Views such as these are still found amongst us, and it remains for the present age to study how out of the obscure beginnings—the primitive and childlike notions of our ancestors—there has been evolved, by slow and painful steps, the modern conviction of a steady progress towards scientific truth.

If any one, counting over the riches of knowledge at his disposal, thinks himself intellectually a self-made man, he is mistaken. Ages ago the first small deposits of truth were made, and in spite of some poor investments, as in astrology and alchemy, there has been an enormous accumulation of facts, especially in recent times when scientific knowledge has fairly compounded itself.

Naturally we do not care to cease accumulating—science never retires from business—yet there is a certain fascination in tracing the family fortunes back to those first settlers of civilization who gained a little knowledge here and there and left a record of it in a rude symbolic image or a curious carving in a rock cave. Compared with the wealth of facts that we now possess our remote ancestors were as poor in knowledge as are the lowest races known at present. But the day of small beginnings is not to be despised and as heirs of the ages and of slowly accumulated capital we should give due credit to the patient thinkers and groping scientists, who built up the fabric of our intellectual fortunes. So in casting up the accounts and balancing the books of other days and races we may throw some light on the views of our own age.

To trace the development of the various views of man's relation to his universe is the purpose of this book. In such a combined history of science and of speculative thought we may see how the two interact. When the scientists make new discoveries, the philosophers attempt to use these as raw materials for building up their systems. On the other hand, when the scientists claim that facts alone can satisfy the human mind, man is apt to demand that these facts shall be woven together into some coherent whole. Thus without the discoveries of the earlier astronomers there could not have arisen any general scheme that took in the secrets of the remoter universe. But when some of the speculators went beyond the facts, as did the alchemists, their notions had to be corrected by the genuine chemists. In other words, science and philosophy must keep step. The following chapters record the various stages of their coöperation in the interpretation of nature.

W. R.

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FROM MYTH TO REASON

INTRODUCTION

The Five Ages

There has been a progress of the human mind in the understanding of nature. We now have a well-settled conviction that the universe is a whole, a great aggregate under the reign of law. How was this conviction reached? How came men to believe in a well-ordered world, a total that could be understood as having rhyme and reason in its working? The story is a long one, for it extends from the dawn of history to the present day.

The matter may be put in the form of a drama in which the ages are the acts and all the world's the stage. These ages are five in number. There is first the Age of Myth, when men believed that nature was ruled by rival gods with the world as their playground. The end of this act tries to reduce these gods to the forces of nature, but the same motive carries over into the second act, the Age of Magic. Here men looked on the powers of nature with fear and trembling. They had a positive terror of its forces, and they filled the world with fabulous monsters. Such a state of mind obtained during the Dark Ages and lasted until the end of the Middle Ages, when the explorers discovered that the ocean was not filled with grotesque beasts and that strange and terrible men did not inhabit the remote parts of the earth. In the third act we have the rebirth of knowledge. Then the scientific discoveries made by the ancient Greeks were revived, and in this crucial middle act characters like Copernicus and Galileo reduced the workings of the universe to natural forces. This leads to the fourth act, where the world is looked upon as a machine, something that can be studied as easily as a working model, a contrivance which man can take apart and understand. But this belief was found unsatisfactory as it left out the great vital element. In the last great act, then, the world is discovered to be alive. It has, as it were, a soul of its own; it is a living machine. In short, the present Age of Evolution completes the drama so far as we are concerned. Who is "we"

The development of the understanding may be considered in another way, from the point of view of artistic conception. The chief historic beliefs constitute a gallery of paintings in which the different schools of thought form a series of pictures, of various schemes illustrating man's ways of looking at the world. Thus, in the Age of Myth the allegorical method was pursued: the phenomena of nature were so many symbols to be interpreted in this way or that. The thunderbolt was the sign of the wrath of Jove, the storm at sea of the anger of Neptune. The Age of Magic furnished even subtler interpretations. Plants were believed to possess "signatures" which signified something in the way of cures. Gems and precious stones were held to bring good or ill luck to the wearer. The Age of Discovery brought a different mood. Like the realistic artist, the naturalist preferred things exactly as he saw them. It was perhaps more flattering to human vanity to fancy, as did the Middle Ages, that the earth was the center of the universe, but an astronomer like Copernicus preferred the fact of our universe being centered in the sun. This was a blow to man's conceit as to his paramount position, but it had its compensations in enlarging his vision, in stimulating his imagination regarding the immensities of space.

Still, it is possible to have a view of the world that is too realistic, too literal. As the next age showed, if the world is a machine and man a part of that machine, his rôle is insignificant, he is not the mainspring but a mere cogwheel. As a passive instrument he loses his liberty; his very end is predetermined, for all his actions depend on the coöperation of the other parts. So to portray man's place in nature is merely to offer a piece of draftsmanship, to give a blue print of a factory. For the realistic type of mind this is exact and satisfying; for the idealistic type it is depressing. Against this view, then, there was a decided revolt. An outburst of optimism painted nature in bright colors and made man the monarch of all he surveys. As there is a romantic art, so also is there a romantic philosophy, and in the age preceding that of evolution we find science becoming sentimental and man regarding nature as a generous nurse, a bountiful mother. Rousseau and his followers were responsible for this rosy picture. Much is made of the kindly fruits of the earth, of the beneficence of the seasons, and humanity thus becomes the final object of all of nature's endeavors.

This optimistic way of looking at life was shattered chiefly by one thinker. Darwin with his doctrine of natural selection showed that man is no more the favorite child of nature than he is the darling of the gods. Instead, he is the product of a harsh selective process, marked by a life-and-death struggle for existence. He may be called the highest example of the survival of the fittest, but this is only because he has fought his way up the ladder of life. He is at the top because he has taken his chances and has played the game. Now the old romantic school, the complacent optimists, did not and do not like this picture. But to one looking the facts in the face it seems more like real life than some fanciful picture of the Swiss Family Robinson on their happy sheltered island. It has in it the thrill of conflict; it appeals to the spirit of ambition. A poet like Tennyson may represent this view as one of a charnel house; he may be repelled by the picture of nature as "red with tooth and claw." Yet the picture may not be as dark as it has been painted. It does not necessarily engender the mood of pessimism.

From myth to reason—here are some of the varied interpretations and contrasting moods evoked by man's outlook upon his environment. In this panorama the scientists have furnished the pigments and the philosophers have painted the pictures. Realists and idealists, optimists and pessimists, all have had their turn, but when the speculative thinkers have gone too far and have become wrought up over some particular system, science has come in to cool the brain. It is the dispassionate view of nature that now holds the field. The Age of Evolution is one in which man has the post of an observer, of one, besides, keenly interested in watching the struggle of truth with error. To be in the firing line of the advancement of science is highly exciting. The fight against erroneous views is as real as any battle. Forces of opposition and bigotry are still here and still active, but at the present juncture to attempt to suppress any working hypothesis, such as organic evolution, is to play the part of one afraid to face reality. It heartens us, however, to find that conceited and complacent views of man's place in nature have always given way to the advancement of learning. As Lord Bacon once said, in his attack on the idols of false belief: "Man being the servant and interpreter of nature, can do and understand so much and so much only as he has observed in fact or in thought of the course of nature; beyond this he neither knows anything nor can do anything."

BOOK I

The Age of Myth

§ 1. *The Beginnings*

The first hints of the idea of order in nature are to be found in the records of the men of the New Stone Age. At a time roughly estimated at twenty thousand years before the Christian era there appeared in place of carvings of animals certain circles or crescents which suggest a recognition of the sun and moon in their seasons. But it is a long leap to the first calendar. It took until the very end of the Stone Age, more than fifteen thousand years later, for the first beginnings of a time record. About 4700 B.C. the Babylonians had a chronology which divided the year into twelve months of thirty days each, and the week into seven days, the latter named after certain deities, as with us in our Wednesday, the day of Woden, Thursday, the day of Thor, and so on. We are apt to take this time division for granted, forgetting that it represented a great deal of painstaking labor. Probably for thousands of years the astronomer-priests on the banks of the Tigris and Euphrates were observing the courses of the stars, the rising and setting of the five planets, for these, along with the sun and the moon, comprised those seven sacred heavenly bodies which gave the sacred seven days of the week. In the same way the priests carefully observed the waxing and waning of the moon and struck the average of thirty days in the month.

The men of Mesopotamia, the region between the rivers Tigris and Euphrates, had an early glimpse into the order of nature in a calendar which served as a time table for practical needs from the planting of crops to the paying of taxes. But it took further effort to correct a glaring error in the estimate of the year's length. A year based on the lunar month was over five days short, so the calendar was adjusted by inserting an extra month every three or four years, as need arose. Since the calendar ran ahead of the sun, arbitrary methods had to be used to correct it. Thus a letter of the famous King Hammurabi, about 2200 B.C., decrees that, "As the year has gone wrong, let the coming month be registered by another name, and let the payment of taxes falling due in this month be paid in the later month."

But even before this another nation of river dwellers had discovered the true method of time division on a solar basis. In the year 4241 B.C., at what has been called the earliest dated event of human history, the Egyptians introduced a calendar of twelve months of thirty days each, plus five feast days. As with the Babylonians, the Egyptian calendar was based on the observations of the temple astronomers, but on observation made with greater exactness. This was due to a peculiar circumstance. It was found that the time of the summer solstice, the longest day in the year, corresponded very nearly with the rising of the waters of the Nile, and that the summer solstice could be determined by what is called the heliacal rising of Sirius. This meant that there was a certain spot on the horizon where the dog star's rising corresponded with the sun's rising. This spot determined in certain cases the structure of the sacred buildings. For example, the immense hall-ways that ran through the temple of Karnak and formed its chief avenue of access made a kind of telescopic tube through which the beams of the sun's most northerly rising were directed.

The curious coincidence between Sirius, the sun, and the rising of the Nile made for exactness in observation, yet the real purpose of this early astronomy was practical. The time of the coming of the "River God," as the phrase went, was of immense importance to the farmer who depended upon irrigation for the success of his crops. But of course the priests attempted to throw an air of mystery about the whole affair, and many temples were erected which were oriented with regard to the point at which the sun rises on the day of the summer solstice.

§ 2. *Fact and Fable*

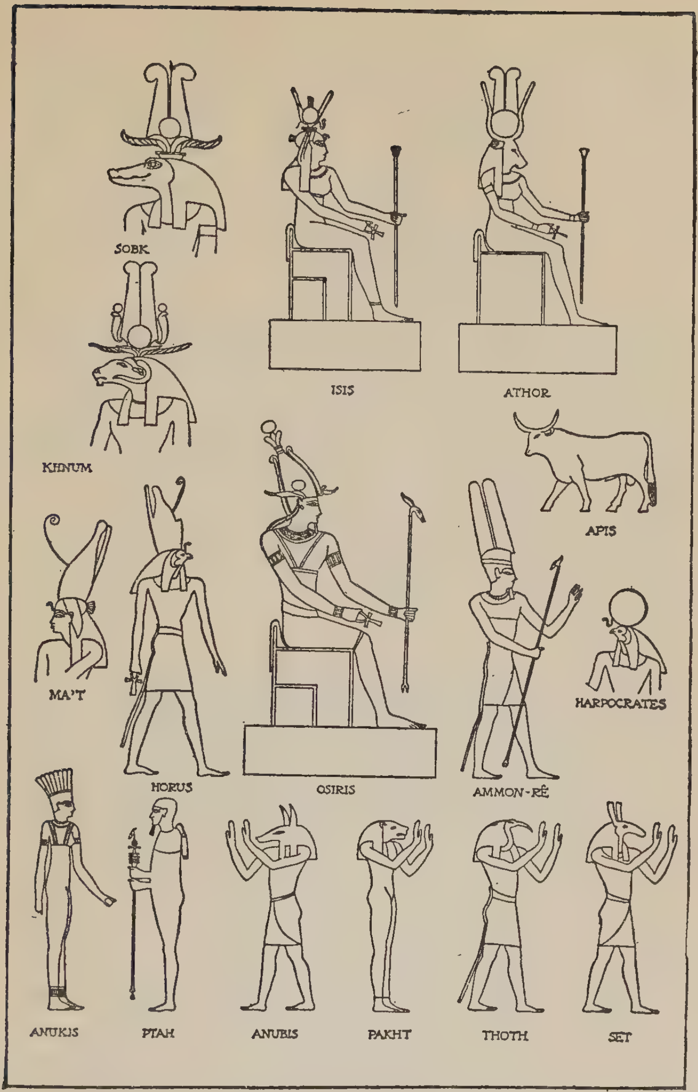
Practical mathematics had something to do with the erection of temples in the region of Heliopolis, the City of the Sun; but how much mathematical lore lay hidden in other sacred structures is another question. The great pyramid of Cheops has been considered a sort of mine of information as to the wisdom of the Egyptians. It is claimed that four equilateral triangles formed the four surfaces of the pyramid proper; that the ratio of the side to half of the height of the pyramid was nearly the ratio of the radius of a circle to its circumference; and finally, that the elevation of the passage leading to the principal chamber was approximately 30 degrees north, or the latitude of Cheops. Unfortunately exact measurements do not bear out these suppositions as to the esoteric learning of the pyramid builders.

Nevertheless the Egyptian engineers handled successfully many difficult problems of practical mathematics. They carried a straight line over the bends of the Nile, and the remains of the ancient nilometers, or water-level marks, disclose the remarkable fact that they are all in one plane over the seven hundred miles from the Delta to the First Cataract. In commercial matters the Egyptians were able also to measure the contents of their granaries, and certain temple records of tribute from subject tribes disclose reckoning in whole numbers from hundreds up to millions. In short, before 1000 B.C. Egyptian mathematicians had developed much that was practical, from calendars to commerce, but mingled with this were certain absurdities. For instance, in arithmetic, if they wanted to express "three-fourths," they said, "one-fourth, and one-fourth, and one-fourth." They were equally shallow in their geometry. Any schoolboy knows how to compute the area of a triangle, but the way the Egyptians did it was to say that the area was equal to the product of any two sides. A calculation like this would naturally lead to a great deal of confusion.

§ 3. *Early Creation Myths*

The Egyptians reached a certain point beyond which they did not seem able to go. In their mental arithmetic they could not multiply by a number larger than two, and they never gained a clear idea of complex fractions. They made their every-day calculations in a long and laborious way and did not gain the short cut of algebraic symbols such as the Greeks discovered. It has been declared that most scholars would agree with the verdict that the Egyptians showed no real love of truth, no desire to probe into the inner nature of things. This lack has been attributed to their extreme conservatism: rather than consign anything to the scrap heap, they would spare no pains, however fantastic, to reconcile two different sets of beliefs. [illegible]

In explaining the workings of the heavens and the structure of the earth the Egyptians preferred mythology to mechanics. Thus the sun god is identified with the falcon-headed Horus, the sun being thought of as a falcon flying through the skies. This solar myth was doubtless connected with the ancient worship of the falcon as a tribal totem. Further traces of such archaic beliefs are found in the recent excavations in the tomb of King Tut-ankh-amen with its strange figures in the burial chamber; here are represented the human body with a head of a dog and the hippopotamus with the head of a clown. The great number of gods worshiped by the Egyptians is



Courtesy of The New International Encyclopædia.

THE GODS OF EGYPT

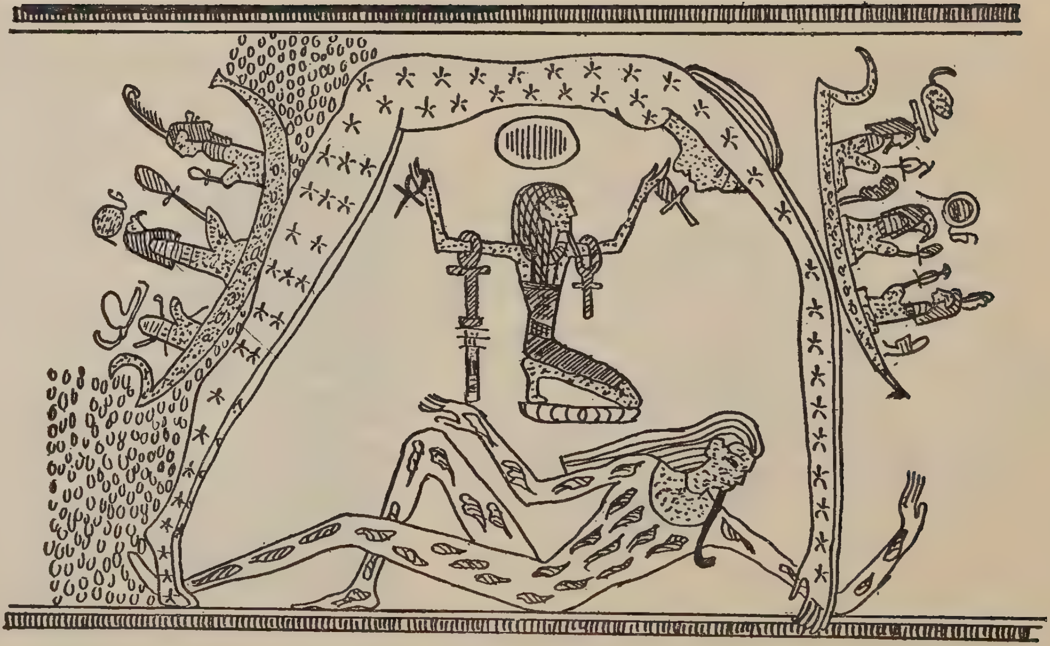
probably to be explained in the same way as the great number of fantastic figures on an Alaskan totem pole: as the original tribes mingled, their totemic symbols were combined. Besides Horus, the falcon, there were Thoth, the ibis god, Anubis, the jackal, Sobk, the crocodile, and other sacred animals, the mummified remains of which can be seen in our museums.

In addition to these tribal gods the Egyptian pantheon had its nature gods, such as Ra, the sun god, Nun, the primeval ocean chaos, and Shu, the god of the air. At this point arises a test of the mentality of the Egyptians. They had some practical mathematicians and mechanics, they also had dozens of gods of different types. But in their explanations of the workings of the world it appears that they preferred the cult of myth to the cultivation of science. Here, then, is one of their widely accepted creation accounts:

> In the beginning Heaven (Nuit) and Earth (Sibu) rested in close embrace in the primordial waters (Nun). On the day of the creation a new God, Shu, arose from the waters, seized with both hands the Goddess Nuit and lifted her up. She now forms the star strewn firmament, supporting herself on her hands and feet, the four pillars of the firmament.

As we have criticized the wisdom of the Egyptians, so also can we criticize the Babylonians and the Assyrians when they come to the problem of explaining the creation of the world. These wise men of the East were not as wise as they were supposed to be. They are said to have been the original teachers of the Egyptians, but their creation myths are just as strange and fantastic as those of the dwellers on the Nile. We must, of course,

THE SUN-GOD RA RISING DURING THE CREATION FROM A BLOSSOMING LOTUS FLOWER



EGYPTIAN REPRESENTATION OF THE EARTH

The goddess Nuit, as the over-arching sky, and the god Ra, in his boat, representing the rising and setting of the sun give them credit for making accurate observations of the movements of the stars and planets, of eclipses of the sun and moon. They observed well, but their explanations were fantastic. When we compare the Egyptians' creation myth of the Goddess Nuit with the creation myth of the Babylonians, we see that the latter is just as fanciful and also has an added note of terror. This myth runs as follows:

MARDUK ARMED WITH LIGHTNING KILLS TIAMAT

Before heaven and earth existed there was only Father Apsu (the Ocean) and Mother Tiamat (Chaos). From the union of Apsu and Tiamat arose the gods. But when Tiamat beheld the hosts of the gods encroaching on her territory, she created monsters to defend her domain—bulls with men's heads and dogs with fish tails, but none of the gods dared fight these monsters except Marduk. With his bow, spear, and thunderbolt he pursued Tiamat and caught her in his net. When she opened her mouth to devour Marduk, he threw the hurricane into her throat and entrails and she burst. Out of these fragments Marduk then refashioned Tiamat's body. But then he had orderless Chaos on his hands, so he split this into two halves—as one does with fishes which are to be dried—then he suspended the one half up high, and that became the heavens, and the other half he spread underneath his feet, and that became the earth; and thus he made the world as man has known it since.

§ 4. *Early Greek Notions of Nature*

When we pass from the Egyptians, Assyrians, and Babylonians to the Greeks, it seems as if a fog were lifting; we have been groping about in the dark, but now the sun of science is beginning to rise. The Greeks have always had the reputation of being clear headed. This quality was shown by the earliest of their thinkers who speculated about the world.

There is an ancient list of the seven wise men of Greece, the first of whom was Thales of Ionia in Asia Minor (*c.* 640-550 B.C.). The interesting thing about him is that he formed a point of contact with the peoples we have just been describing. He actually traveled to the Euphrates and the Nile and interviewed the priests of these regions. From the former he learned considerable weather lore and star lore, but what he did with this learning is the important thing. He did not fall down and worship strange gods or consider that the stars in their courses had any mysterious influence upon people or events. What he did see was that the wonders these ancient worthies observed could be explained in a scientific way.

It is not so important that Thales astounded his fellow citizens by predicting a total eclipse of the sun on May 28, 585 B.C., as that he asserted that solar eclipses were caused by the moon passing between the earth and the sun. An eclipse was not a dire portent, threatening the fall of kings or some great calamity, but a natural fact to be explained by natural causes. The Babylonian priests had known that eclipses occur in cycles and so were able to predict them, but they were wont to explain them as omens and warnings, just as they utilized other astronomical knowledge in the way of astrological advice. Thus they claimed that the heavenly bodies by their movements offered to men much secret information, an eclipse presaging a disaster to the royal army, a comet the coming of the plague. Naturally the priests kept such secrets to themselves but they were willing to sell them for a consideration. If a king were going to war, they would tell him that the stars in their courses would fight for him, or, descending in the social scale, they would cast a horoscope for a farmer in order to tell him the right time to plant his crops.

Thales may have gained some practical knowledge of eclipses from the Babylonians, whose baked clay records are still extant, but he obtained no scientific knowledge of astronomy from the banks of the Euphrates any more than he learned the science of mathematics from the banks of the Nile. Indeed, the tradition is that he taught the Egyptian priests certain general principles of which they were ignorant. He showed them, for instance, how to measure the exact height of one of their pyramids. He explained that when a man's shadow is the exact length of his height, in the same way, and in the same moment, the shadow of the pyramid is equal to its height.

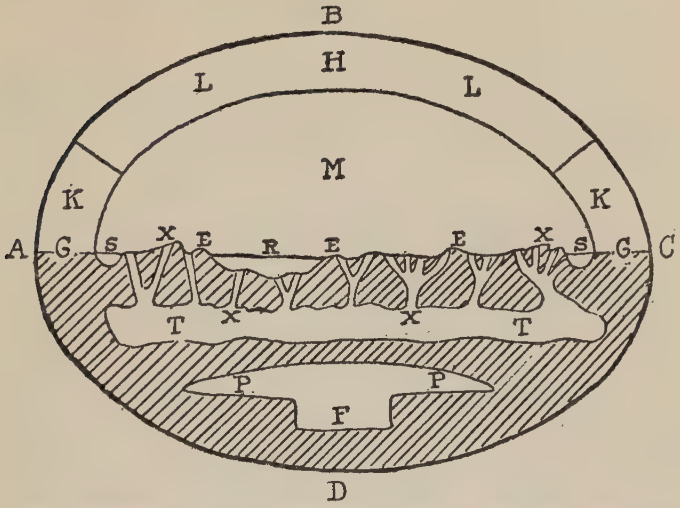
This approach to a problem was most significant. The Egyptians were able to measure certain figures and solids, but only in the way of concrete cases. The Greek thinker made the advance from the concrete to the abstract, from rule of thumb to the rule of reason. Where the Egyptians stated everything in terms of the particular problem, he advanced from the particular to the general. The "rope measurers" of the Nile depended upon the dimensions 3, 4, 5, to determine a right-angled triangle; Thales was the first to suggest a geometry of lines and thus offered theorems which would solve whole classes of concrete problems. Besides the measurement of pyramids, tradition has it that he was able to estimate the distance of a ship off shore, his method here being the same in principle as that by which range is determined in a modern battleship.

THE EGYPTIANS MEASURED THE HEIGHT OF THE PYRAMIDS BY THE SHADOWS CAST ON THE DESERT SANDS

Another advance made by this early Greek philosopher was in regard to the structure of the world. Here there was a change from a theogony, or a world ruled by gods, to a cosmogony, or a world governed by natural principles. The priests of Egypt and of Asia Minor looked at the workings of the universe in fear and trembling, but Thales, instead of believing in rival gods who threw hurricanes at one another and split the entrails of their enemies, declared that the gods have little to do with the forces of nature. He even went so far as to deride the divinities in that Greek Bible, the books of Homer. One reason for this was that these divinities were quite arbitrary; they often changed their favorites among the Homeric heroes, just as they were capricious towards the common people. The ordinary man could never tell what they were going to do; they might increase his health and wealth or they might wantonly destroy his body and crops.

Instead of offering praises and sacrifices to the gods of the four warring elements earth, air, fire, and water, Thales considered what part was played by the elements themselves and particularly what natural element was the foundation of all being. This element he believed to be water and for this belief various reasons have been given. According to Aristotle (384-322 B.C.) Thales selected water because he saw that the nourishment of all beings is moist, that warmth itself is generated from moisture, and that the germs of all living things are of a moist nature.

Thales left no writings, but the greatest of Greek philosophers thus interpreted his reasons for his choice of the fundamental element. Others have given further reasons, declaring that Thales emphasized water because it could take three forms: a liquid in its natural state, a solid as ice, a gas as vapor. Here environment played its part. The thinker of Miletus had the waters of the sea before him, he had the mountains with their ice behind him, and the clouds in the sky. He also observed



HEAVEN, THE EARTH, AND THE ABYSSES ACCORDING TO THE WRITERS OF THE OLD TESTAMENT

ABC, the upper heaven, ADC, the curve of the abyss; AEC, the plane of the earth; SRS, various parts of the sea, EEE, various parts of the earth; GHG, the profile of the firmament, or lower heaven; KK, storehouses of the winds; LL, storehouses of the upper waters, of snow, and of hail; M, the space occupied by the air, within which the clouds move; TT, the waters of the great abyss; XX, the fountains of the great abyss; PP, Sheol, or limbo; F, the lower part of the same, the inferno, properly so-called.

that water was an absolute necessity in many parts of his land. In the back country of Ionia irrigation had made the desert to blossom like the rose. Then, too, he had heard through the sailors who entered the harbor of Miletus of a great stream called Oceanus which lay beyond the pillars of Hercules, now known as the Straits of Gibraltar, and flowed around a world which was thought to be flat like a saucer. And there was a further myth that this saucer-like earth rested upon the waters, a belief in the waters under the earth not being confined in those days to the Hebrews alone.

Such are the reasons given by the authorities, ancient and modern, for Thales' choice of water as the fundamental principle, the element from which all the rest are derived, the antecedent from which they have sprung and into which they will finally resolve. Ocean, or the universal encircling sea into which all waters flow, is more than a myth, it is a scientific symbol. The conception at least marks the first step in the path of rational explanation, and that step was to seek a natural and not a supernatural cause. No gods are called upon to explain the various changes in nature; impersonal forces are deemed sufficient. Instead of asking *who* sends rain, thunder, and earthquakes, the question now is *what* are the antecedent causes of these phenomena?

§ 5. *One Element Not Enough*

As there was strife among the elements, so was there strife between the early philosophers of nature. Thales took water to be the primordial substance and sought to obtain a monopoly in the market of speculation, but a rival soon arose. Heraclitus of Ephesus (535-475 B.C.) chose fire as the superior potency, at least in a symbolic way. To him a law governed the flux, the institution of things, and this law was represented by the ever-changing yet constant flame. Heraclitus was known to the ancients as the obscure philosopher, nevertheless his thoughts may be made fairly clear. Cosmos, or order, he declared, is the same for all things; no gods nor men have made it, but it always was, and is, and ever shall be, an ever-living fire, kindling according to fixed measure, and extinguished according to fixed measure. Furthermore, the transformations of fire are, first of all, sea; and of the sea one-half is earth and the other half is lightning flash. Finally, all things are exchanged for fire and fire for all things, as wares are exchanged for gold and gold for wares.

As the ancient interpreters explained all this—and they probably possessed fragments lost to us—Heraclitus meant that all things arise from fire and all end by becoming fire. As this fire is quenched, all things come into the order of the universe; for the first, the dense part of it, contracting into itself, becomes earth; then the earth becoming relaxed by fire is rendered water in its nature; then it is sublimated and becomes air, and again the universe and all bodies are consumed by fire in the conflagration.

Echoes of these doctrines are familiar to us in the ancient beliefs that fire is the vital element needed by plant, beast, and man; that there is a central hearth of the universe; and that in the last days the elements shall be melted in a fervent heat. This last doctrine has a suggestion of modern speculation, such as the nebular hypothesis, according to which the universe originated in a primeval fire-mist, goes through countless changes, and returns again to fire-mist.

This process of picking out one or another of the four elements as the superior did not stop with the second element. Anaximenes (588-524 B.C.), another of the Milesian philosophers, selected air, and he reasoned in much the same way as his predecessors. He declared that without air no living creature could draw a breath; further, the earth itself seems to breathe, as is shown by the breezes and the winds which circulate over its surface. All this is obvious, but the resolution of the elements into air is dubious. It seems that Anaximenes explained the different forms of air as follows: When it is of very even consistency it is imperceptible, but it becomes evident as the result of cold or heat or moisture, or when it is moved. It has a different appearance when it is made more or less dense; when it is expanded into a thinner state it becomes fire; on the other hand, winds are condensed air, and air becomes clouds by compression, and water when it is compressed still further, and earth and finally stones as it reaches the limit of condensation.

This scheme, as it has come down to us, is not very clear and could hardly have been satisfactory. To resolve one element into another until air at one end of the scale becomes stone at the other is a reduction to an absurdity. The trouble, then, with the partisans of this or that particular element is that each assumes that his primary principle is fundamental and can be transformed into all the rest. If this be so, further absurdities arise. If stone is made of air, why may not iron be made of wood? In view of these difficulties it is surprising to go back and find that a previous thinker had made a logical leap and boldly reached beneath all the elements in the search for some more general substance. This was done by Anaximander of Miletus (611-547 B.C.). The remarkable fact is that this companion or pupil of Thales really anticipated the rival claims of the other and later Ionian thinkers. According to his speculations, instead of a war of the elements there should be peace, since all would be unified in a common existence; instead of the structure of the world being explained by this or that particular element with its limited powers, some universal substance would explain them all. To this was given the peculiar name of the Boundless. To many this term has seemed as vague and useless as the Unknowable of Herbert Spencer, that mysterious power from which all objects are supposed to be derived. But in justice to the ancient Greek thinker we must grant that the something called the Boundless had its good points. The elements were limited in scope and power, but the Boundless was declared "immortal and indestructible, surrounding and directing all." As Aristotle put it, the elements are mutually antagonistic to one another, inasmuch as air is cold, water is moist, and fire is hot; if one of these were infinite, the rest would be at once blotted out.

§ 6. *The Elements Combined*

In his universal principle, the Boundless, Anaximander had gone too far afield. However, the four elements could be used as a working hypothesis provided some sort of unifying principle were brought in. This was done by a philosopher of western Greece, Empedocles of Sicily (495-435 B.C.), who made a sort of combination or partnership of all the elements and in that way gained something more complicated, but really more workable, than a state of merely reckless competition. The elements he compared with the colors on an artist's palette —"many-colored pigments which the painters work with and blend together harmoniously, more of one and less of another, till they produce likenesses of all things."

This is a human analogy, since nature to Empedocles worked somewhat as does man. The creative principle is variously called Harmony, Attraction, Perfect Love, "whereas the immortal elements came into being as mortal things, and as they were mingled together there flowed forth the myriad species of mortal things, patterned in every sort of form, a wonder to behold." But this is only one side of the picture. Besides the principle of Harmony the principle of Strife is at work in the world. In the immortal cosmos "whatever things are friendly are united —the beaming sun, and earth, and sky, and sea—but in the mortal realm whatever things are hostile are separated by baneful Strife." Human members may in the prime of life be fitted together marvelously by the "glues of Harmony," yet at another time, "separated by evil Strife, they wander each in different directions along the breakers of the sea of life."

This remarkable poetical description goes on to explain the further development of life. Fragmentary creatures which sought to gain a footing on the shore of life did not succeed until combinations arose containing inner Harmony. But Strife ever lay in wait and the world drama became a cyclical rise or fall, a continuous process of balance and adjustment between rival powers, between "bloody contention and Harmony of sedate face." Man himself was at the mercy of the elements, for these had to be in exact proportion to ensure life, as natural man is made up of parts which exist in the rest of nature. Earth is the solid part of his body, water the liquid, air his vital breath, and fire his spirit. His very intelligence comes from combining these elements. He perceives all these things because he is everything. The fire in his eye perceives fire, the air perceives air. In a word, "like seeks like."

Some have read into this description an anticipation of modern science, a conception of organic substances being made up of various combinations and permutations of the chemical elements carbon, hydrogen, oxygen, and nitrogen. This is going too far, but there was one portion of Empedocles' speculations which had a long and curious history. The notion that by earth we see earth, by water, water, and "by air, glorious air," logically leads to the doctrine of the affinity of the elements within man to the elements outside man. This notion survives to this day in the saying that "like cures like." In the case of Empedocles the tradition is that he carried this principle to extremes. When he found that the fires of youth had died out, he thought that he would replenish them by going to the central fire. It happened that Mount Ætna was not far off, so, according to the fable, he proceeded to jump into the crater of the volcano. There is a further embellishment to the story that the mountain, in contempt for his boldness, threw back his brazen sandals.

§ 7. *The Elements Subdivided*

Empedocles with his four elements and two rival powers, Harmony and Discord, left the problem of this earth, "the divine ball," in a somewhat confused state. A further step was taken by Anaxagoras of Clazomenae (500-428 B.C.) who was brought by Pericles to Athens and there remained for thirty years. This thinker from Ionia considered matter to be divided into invisible particles which he called "seeds." Now the seeds or sub-elements are described as being subject to the same principles of attraction and repulsion as the elements themselves, but, it was added, "over all is mind, the ruler."

In the theory of Empedocles all creatures appear to be at the mercy of the elements, since the chances are equal between Discord and Harmony. But in the conception of Anaxagoras there is a guiding principle to keep the elements in order and prevent their going astray. Not only does the mind of the world rule the smallest seeds, but it rules the whole revolving universe and has ruled it from the beginning. This mind or Nous, as Anaxagoras put it, "is the most rarefied of all things and the purest, and it has all knowledge in regard to everything and the greatest power; over all that has life, both greater and less, mind rules. And mind ruled the rotation of the whole, so that it set it in rotation in the beginning. First it began the rotation from a small beginning, then more and more was included in the motion, and yet more will be included. Both the mixed and the separated and distinct, all things mind recognized. And whatever things were to be, and whatever things were, as many as are now, and whatever things shall be, all these mind arranged in order; and it arranged that rotation, according to which now rotate stars and sun and moon and air and ether, now that they are separated."

Anaxagoras may have been led to his theory of revolutions and separations from the great fall of meteorites of 467 B.C., for he mentions one specimen as large as a millstone. At any rate he speaks of the sun, the moon, and the stars having assumed their present positions by "hurlings off" from the pole star, which to him was the center of the universe. All this has been compared with the theories of Kant and Laplace, over two thousand years later, which sought to explain the formation of the solar system by revolving nebulae. But even in Anaxagoras' suggestive idea there was a defect. The "mind" that is talked about is outside of the seeds or little particles of matter. If that be so, there is no way for man to discover how these seeds are going to act. As he studies them he might judge that they act of themselves, just as a child might think that the puppets in a marionette show act of themselves. But if the ruling principle can be put inside of the little particles and we can discover what that principle is, then we have the last necessary step to a true understanding.

§ 8. *The Elements Turned into Atoms*

This step was taken by those who advanced the theory of atomism, Leucippus (*c.* 490-430 B.C.) and his pupil Democritus (*c.* 460-350 B.C.), both of Thrace. Of the latter we know the most. In his book *The Great Order of the Universe* he emphasizes natural forces immanent in matter itself. Motion does not come from outside, as if one ball were struck by another, but the smallest particles of matter, atoms themselves, possess motion of themselves and have always possessed it. This motion was original and eternal, and these "indivisibles," infinite in number, have through untold ages been undergoing countless combinations. If you study their ways they can be understood, for the laws of nature have been carrying on the sifting process for all past time. Thus the reason why we find that like seeks like is due not to supernatural but to natural causes. Nature acts as does the farmer with his winnowing fan "where barley lies next to barley and wheat to wheat," or like the ocean "where the movement of the waves flings long stones next to long stones, and round pebbles to round pebbles."

The wandering elements of Empedocles are now brought under law and order and at the same time reduced to their smallest size—to a point where as atoms they literally cannot be cut up further. These two steps are important advances on the road of science.

The sifting processes remind us of the natural selection of the modern evolutionist, and the reduction of matter to indivisibles of the fact that it was not for twenty-five centuries, and until the present generation, that the atom was still further split into its constituent protons and electrons.

The highly interesting feature of these early speculators about the elements is that they accomplished so much in only one hundred and fifty years—in about the length of time that has elapsed since the founding of the American Government. And just as the American Republic is a union, made up of separate sovereign states, so the universe, according to the atomists, was a whole made up of separate self-governing units. This was a good working hypothesis and it did a great deal in the way of practical explanation. People were puzzled as to how matter disappeared and as to where it all went. Here is a ring on the finger that wears out, or a great stone on the seashore that grows smaller and smaller as the waves beat upon it. Where does it all go? Democritus answered: "You cannot see the process of wastage, but you know the bits are not lost, for gold dust or sand remains." In this way the atomists solved the problem of the persistence of matter. The form may change, but the stuff remains.

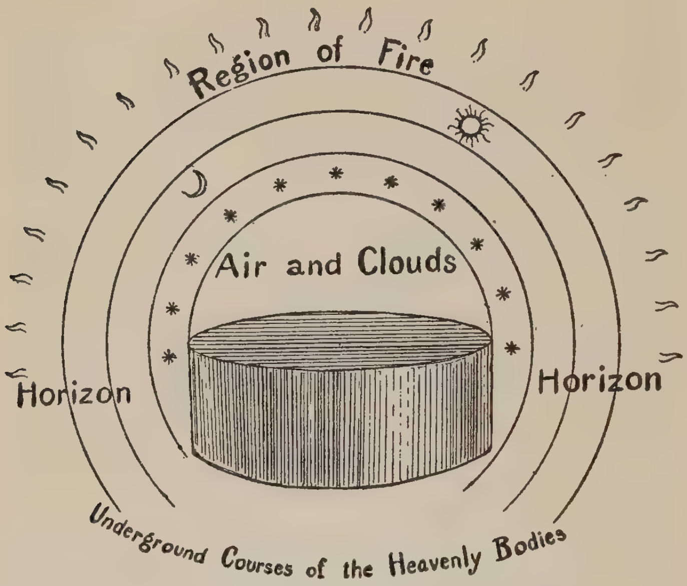
With their indivisibles the atomists could also explain the reconstruction of bodies. This is the illustration that was given: "Take the first and the last letters of the alphabet, A and Z. With these you can make three groups or combinations and with these groups you can go very far. For example, the group according to shape gives us A and Z. Next, the group according to arrangement gives us AZ and ZA. Finally, the group according to position gives us A and N, because in this last case you have put the letter Z on its side. Start again and you have three letters instead of two and out of these you have a still greater number of combinations that can be made."

Atomism was an efficient instrument in the advancement of knowledge and within a comparatively short time the great Roman thinker Lucretius (*c.* 99-55 B.C.) took this theory and gave a fair working model of the universe in his poem entitled *Concerning the Nature of Things.* But since in this poem he anticipated to a certain degree the modern doctrine of evolution, we must go back and endeavor to see how the Greeks solved this last great problem. They had practically solved the question of *what* the world was made of, and the final answer was the atom. They had next to solve the question *how* the world was made, and here the help of geography and history came in.

§ 9. *Working Models of the Universe*

The first group of Greeks had solved the problem as to *what* the world was made of. They had now to settle *how* the world was made. The first group started with crude elements and ended with the smallest of particles —the atom. The second group now reversed the process and went from the small to the large. The earth, as men first imagined it, was flat like a pancake; as time went on it spread out through discoveries, just as when fresh batter is poured on a griddle. Indeed, within six centuries the known world was enlarged to over three times its former size. It was the voyagers and traders who brought in the new knowledge, a knowledge which was absolutely necessary for the progress of thought. We say now that trade follows the flag; in the old days science followed trade.

The earliest voyagers of whom we have an account were the Phœnicians—near neighbors of the Greeks in Asia Minor. One product they sought was tin, for this was in the Bronze Age and tin was necessary to harden copper. In order to obtain tin they sailed through the Pillars of Hercules and as far north as Cornwall in England. Another material highly prized was amber, known to the Greeks as *elektron,* from which we derive our word electricity. This substance was considered not only precious but mysterious, since it had the property when rubbed of attracting other bodies such as pith balls. In order to find amber the Phœnicians of that day sailed as far north as the Baltic and brought back the fossil gum in the rough. This was made into beads which were supposed to have magic health-giving properties. Details like these are connected with the growth of the world map. In the days of Homer, about 1000 B.C., his hero, the hardy Ulysses, had sailed as far west as Sicily. By the time of Thales, the first of the wise men, the Greeks had passed Gibraltar to the west and penetrated to the east beyond Persia to what was called the Unknown Desert. By 400 B.C. the world map extended from the North Sea to the cataracts of the Nile, and from Gibraltar to India.



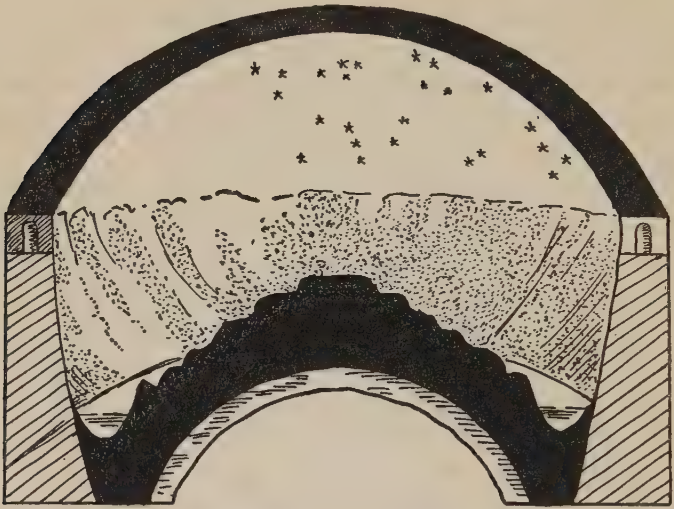
THE UNIVERSE ACCORDING TO ANAXIMANDER

Alexander the Great had reached the Hyphasis and wept because there were no more worlds to conquer.

While sailors and travelers were advancing learning in two dimensions, the natural philosophers who engaged in astronomy were advancing learning in regard to the third dimension. Anaximander of Miletus, pupil of Thales, compared the earth to a vertical stone pillar; this had two surfaces, opposite one another, and on the top surface men were said to dwell. However crude this view, it was an advance over the pancake theory of Homer's day; it gave a real solidity to the earth, which was no longer supposed to be resting upon the waters.

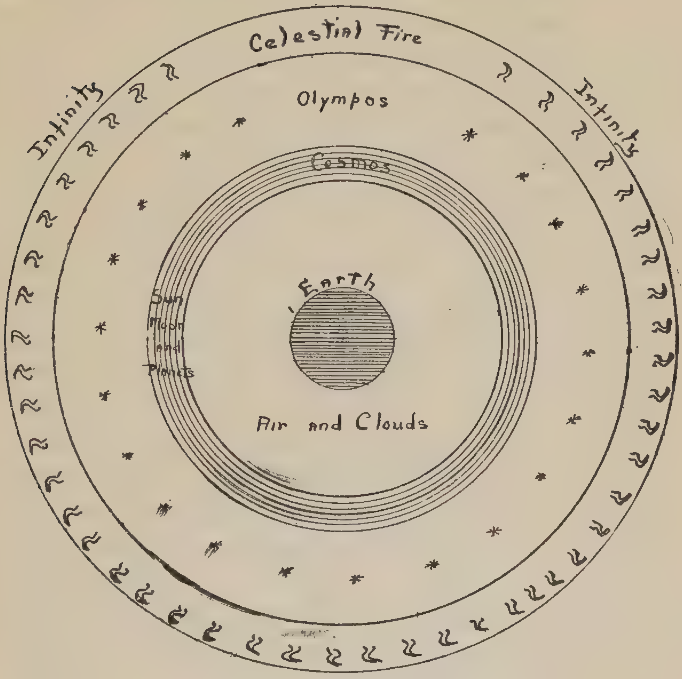
Besides giving the Greeks a map of the earth, Anaximander gave them a globe of the sky. His task was to arrange the various elements and heavenly bodies in some kind of orderly scheme. He did this by putting them in concentric layers: above the sea he put the air and the clouds, then the stars with moon and sun, and lastly the region of fire, the successive heavens being, as he said, "like the bark enclosing a tree." This seems very obvious because it goes in almost regular order from the denser elements to those less dense. But something else was needed, and it was finally suggested that what we see above our eyes is only half of the complete sphere. The child of to-day is taught early that the visible sky is a hemisphere, but in those days it was a distinct advance to say that the dome of heaven over our heads means that there is also a dome beneath our feet, and that down below us lie the underground courses of the various heavenly bodies.

All this had a destructive effect on the theories that had gone before. One notion was that the sun was kindled afresh every morning; another, held by the Babylonians, was that at night it ran back from west to east in a dark tunnel. A third notion was that of the Egyptians, who supposed the sun to be carried over the sky in a self-propelling boat; they pictured a sort of canoe in which the orb of day is carried, while the oars at the stern seem to go of themselves. The Egyptians had also another belief, that there was a great mountain to the north behind which the sun went back to its place of rising in the east, a curious conviction revived later by one of the Church Fathers, Cosmas.



BABYLONIAN CONCEPTION OF THE WORLD AS A BELL-LIKE VAULT, CREATED BY THE GOD MARDUK. THE SUN RETURNS AT NIGHT THROUGH THE TUNNEL AROUND THE HORIZON

All such theories were now left behind. A great advance was made in Anaximander's teaching that the sun describes a complete circle in the sky. But one false point remained, namely, the belief that the earth was at the center of the universe. The true theory, the sun-centered theory, was hit upon within five hundred years, but it remained practically neglected until about the time of the discovery of America. Of course, the men of old seemed to be right in holding that the sun moved in the sky and revolved about the earth. They trusted their eyes and appealed to common sense. But in addition they brought in the aid of fancy, assuming that the sphere was



THE UNIVERSE OF PYTHAGORAS

the most perfect of figures, that the earth was the most important spot in this sphere—therefore, the earth must be at the center of all.

Another curious reason given for this geocentric belief was that mankind is at a central position and surrounded, as it were, by a celestial orchestra. Pythagoras (*c.* 582-500 B.C.), the mathematician and musician, claimed that the seven heavenly bodies—the sun, moon, and the five planets—are arranged in a kind of musical scale at intervals proportional to the seven chief notes of that day. These heavenly bodies form the cosmos proper and as they move, give forth music—"the music of the spheres." When the objection was raised that men do not hear this music, the answer was given that this is because we are so used to this heavenly harmony that we do not notice it, any more than a man dwelling near a cataract would notice the sound of its rushing waters.

We have now to reconsider the ideas of those two groups of thinkers, composed of the trio who were largely wrong and the trio who were largely right. Following Pythagoras with his heavenly harmony, Plato, as we shall see, presented a view based more on fancy than on fact. His scheme was less that of astronomy than of theology, or poetry about the gods. Indeed, Plato went so far as to consider the heavenly bodies as a host of immaterial intelligent beings, since "the framer of the universe had distributed souls in proportion to the stars, and assigned each soul to a star."

§ 10. *Plato's Poetic Cosmos*

It is curious to observe how a purely mechanical theory evolved by the early natural philosophers was reinforced by the speculative philosophers. The human mind does not proceed in straight lines. It likes to leave the narrow path of fact and wander in the fields of fancy. The direct line of scientific speculation was deflected with Pythagoras. When this founder of a secret society began to talk about the principle of harmony as ruling the universe, when he made the stars the abodes of gods, the age of myth was revived. Pythagoras' follower Plato (427-347 B.C.) was largely responsible for turning back the clock of scientific progress. To explain the workings of the world he preferred imagination to observation. There is, of course, no advance in science without theory; as with a track-laying machine the rails must be placed ahead before they are tested. But in Plato's case there was too much theory. The early thinkers had dealt with the material, he preferred the spiritual. They had got rid of a flat earth, of the earth as a pillar, and reasoned that the dome of the sky was much larger than men had conceived. This was not enough for a philosopher who was also a poet. Plato sought ultimate principles such as heavenly harmony and a world soul animating all. So he uttered this sentiment: "The embroidery of heaven, though wrought upon a visible ground, is the fairest and most perfect of visible things and it is displayed to our mortal eyes as a pattern of the eternal realities which are granted to the vision of the soul."

This is pure poetry, and that system of thinking, carried out in a dialogue called the *Timæus,* is a great world poem. Just as the wandering Ulysses had sailed through unknown seas and touched at mysterious islands which were later identified on the maps, so with Plato. He touched on occasional facts, but he preferred to sail the sea of speculation. The *Timæus* is the story of the soul's adventure in the vast ocean of the imagination. Timæus is an imaginary character who is introduced to Socrates as "the most of an astronomer among us," and as one who has made a special study of the nature of the universe. Through the mouth of this character Plato presents his own views and constructs a cosmos, or orderly universe, out of the materials furnished by the thinkers who had gone before. These were the eastern Greeks who manipulated the four elements, and the western who brought in the ruling principle of mind and notions of number and harmony.

Such was the raw material. Now comes the finished product. In his story of the creation Plato starts with chaos. The cause or ground of creation is the goodness of the Creator, who seeks to extend his own goodness or blessedness as widely as possible. His motive is that of the artist who wishes to produce a masterpiece. For this there must be not only materials to work with, but models to copy. The materials are the four elements, the models the ideas or eternal patterns existing in the heavens, such as are typified by numbers and geometrical figures. Out of these the Creator makes a world animated by a living soul. Its form is the most perfect form—

that of a sphere, polished and smooth on the outside "as if from a lathe."

As the human soul is the bond between man's spirit and his body, so the world soul is the bond between the ideas and the elements. It is spread through the world like water through a sponge. Infused into the mass of brute matter, it crystallizes into the geometrical forms of the elements: for example, flame, symbolized by a pyramid, has the form of a triangle.

Such is the first act in this play of fancy. The other acts need only be sketched to obtain the plot. Just as Shakespeare used the popular beliefs in ghosts and witches to suit his audiences in the Elizabethan age, so did Plato bring into his philosophy the mythology of his day. He has the elements on his hands; he has also the traditional gods. Besides the world in the form of a perfect sphere—divine, imperishable, and infinitely beautiful—there are other worlds. These are the stars inhabited by the created gods—fire gods fashioned by the Creator and in turn given the task of creating other creatures proper to the other elements, birds for the air, fish for the sea, and animals for the land, including the noblest of animals, man.

By this division of labor many difficulties are avoided. The Creator is not to be held responsible for the freaks and aberrations of nature—for monsters on land or sea, or for man when ugly, base, or depraved. These creatures, especially man, are responsible for their own shortcomings. If man with his god-given mind will not contemplate the celestial ideals, if he will look down and not up, it is his own fault. If he dulls the spark of the divine fire in this life by bringing it in contact with the lower elements, he will suffer punishment in the future. At death, if he has succumbed to the temptations of the flesh, he must undergo punishment. The longer he has dallied with base matter, the longer will be his period of purgation. His soul must migrate to other realms, perhaps wallowing in the mud like Circe's swine or, what seemed still worse to the clever Greeks, assuming the form of a silly bird or a stupid fish.

Thus does Plato picture the total universe—from the dim past, when "all things were originally a chaos in which there was no order, and nothing had any kind of name," to the remote future and the last syllable of recorded time. In age-long cycles the souls of men must undergo transmigration until at last, purified as by fire, a few choice spirits may attain the status of the fire gods and each inhabit a star in the heavens above.

The *Timæus* is a great prose poem, a cosmic drama traced by the moving finger of time. It included among its characters all conceivable beings—the Father who begat the world, the stars moving as in a dance, the earth which is our nurse, man the most religious of animals, living creatures from beasts to plants and "in all implanted the seed of immortality."

This is the very language of Plato, fanciful to modern ears, hard to understand, yet having a profound value. The *Timæus* has been criticized as being an impossible medley, a mixture of astronomy, theology, and natural philosophy, containing fantastic guesses at the truth, a positive hindrance to the advancement of science. It may be all that, but it stands as a real human document. It is to be looked at as a poem embodying the current beliefs, meeting the popular demands much as did Milton's *Paradise Lost,* and just as the Miltonic conception of creation satisfied men's minds almost up to the coming of Darwin and the doctrine of evolution, so did the Platonic conception satisfy many up to the rebirth of science in the fifteenth century. The *Timæus* was admired by the early Church Fathers, reappeared from time to time during the Middle Ages, and was still studied at the dawn of the Renaissance.

§ 11. *The Right Model Rejected*

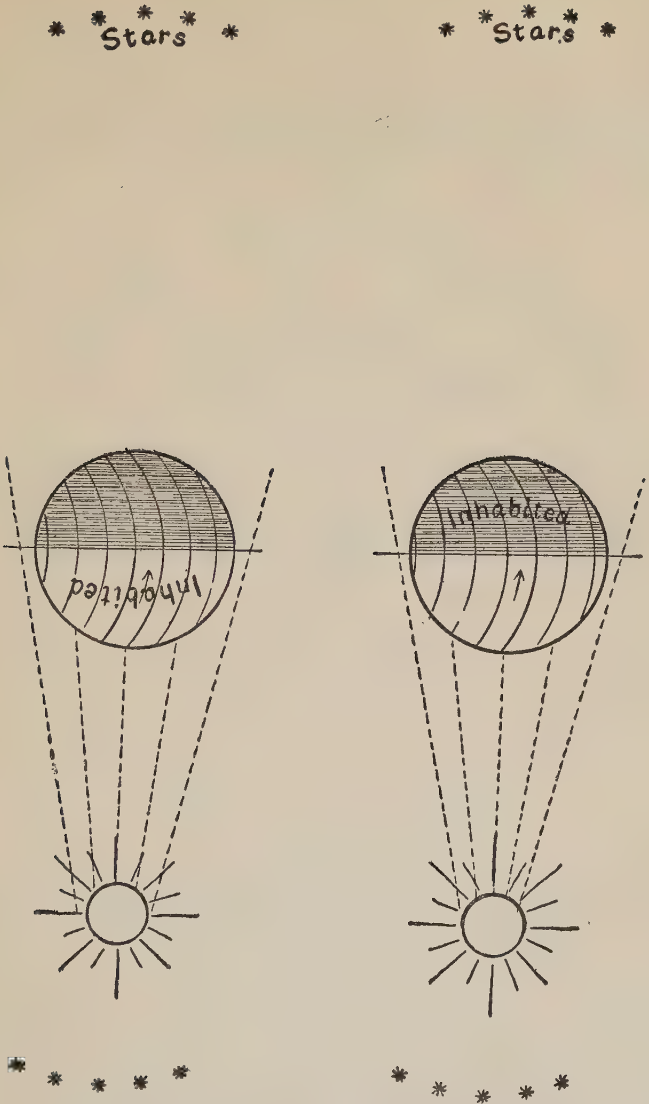
Plato's cosmology was pure poetry, with little observation and no experimentation. His pupil Aristotle (384-322 B.C.) used more observation but was ruled in most cases by preconceived ideas. In his book *On the Heavens* he proved from metaphysics that the earth must be spherical and at the center of the universe. It is spherical because the curved line of the earth's shadow seen on the moon is almost round. This is observation; but metaphysics adds another and stronger argument, namely, that the circle is the most perfect figure because it always returns upon itself. As for the earth being at rest and at the center of the universe, reason says that a state of rest is more perfect than a state of motion and that a central position is the most dignified. Similar preconceived arguments are given for the external form of the universe, the stellar sphere itself, namely, that a sphere is the most perfect of solids, and a solid is more perfect than a surface or line because it is of three dimensions, and these mean completion, perfection.

Reasoning like this simply begged the question at issue and brought about what various authorities have considered a setback, a veritable catastrophe, in the history of astronomy. It was no solution to say that the stars travel in circles because it is their nature to, inasmuch as they receive their motion through the mediation of special beings who may be called subordinate gods or sphere-spirits. Such explanations from myth and not from mechanics have brought the charge that Aristotle, at least in his astronomy, went back to the ideas of primitive man. It is only an enlargement of primitive fetishism to argue that it is spirits that move the planets around.

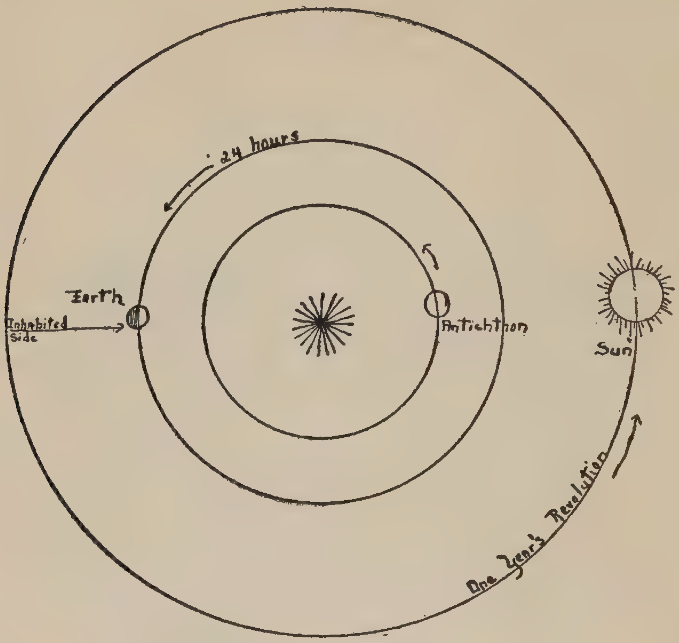
All this is in strong contrast to Aristotle's other works. He confessed that he was not a specialist in astronomy, for he could only depend upon the information of others, but in zoölogy, as will be shown subsequently, he depended upon his own direct observation of animals and has with justice been called one of the forerunners of the idea of evolution. But when Aristotle rejected the doctrine of the earth's motion, in spite of the valid arguments of his contemporaries, it may be agreed with his critics that he was, on the whole, more instrumental in retarding the progress of astronomical science than any other man who ever lived.

Aristotle was on the wrong path in the pursuit of astronomical truth and he was unfortunately followed by that famous Greek thinker, Ptolemy of Alexandria (*c.* 140 A.D.), who systematized the notion of a motionless earth at the center of the universe. But there were other men of Aristotle's time who were on the right path. The Pythagorean astronomer of the Black Sea, Heraclides (*c.* 370 B.C.), asserted that the earth was not fixed but revolved in a turning manner like a wheel fitted with an axis, from west to east around its own center. As we reconstruct the diagram, this would explain how that half of the globe which was inhabited, according to the current Greek conception, would alternately face and turn away from the sun. This daily turning of the earth had been previously suggested by Philolaus, who flourished toward the end of the fifth century before Christ. As a Pythagorean, Philolaus was apt to mingle fact and fancy. He conceived that the earth, like the sun, moon, and five planets, revolved in space. But since the addition of earth to the heavenly bodies would spoil the sacred number of seven, he added two other imaginary bodies, counter-earth (*Antichthon*) and, in the center of the whole system, a central fire variously called "the Watch Tower of Zeus" and "the Hearth of the Universe." These two bodies, plus the sphere of the stars, made a total of ten, another number sacred to the Pythagoreans.

The system of Philolaus was certainly a curiosity, but it had one suggestive idea, that of the central fire. Of course neither the central fire nor the counter-earth was ever discovered in spite of the extension of the ancients' knowledge of the earth, whether to the far east or to the far west, whether by the march of Alexander the Great to India or by the voyage of Hanno the Carthaginian beyond the Straits of Gibraltar. These two celestial bodies may have been fictitious, but the idea of a central fire was fruitful, provided it could be identified with the sun. This identification was made at the end of the third century before Christ by Aristarchus, who has been entitled "the Copernicus of antiquity." It was Copernicus, the Polish astronomer of the sixteenth century, who found out the proper way of looking at the world machine. A machine may be described from any angle, but there is always some particular point at which the observer must place himself in order to understand its workings. This point Copernicus conjectured to be the sun. By imagining himself thus situated he found that all the puzzles



THE REVOLUTION OF THE EARTH ACCORDING TO HERACLIDES of the movements of the planets and other heavenly bodies were solved at a stroke. Just as in a machine certain wheels have apparently eccentric motions when looked at from the wrong point of view, so it was with the world machine. The Greeks had been gazing from the wrong place, for they actually gave the name of planets or "wanderers" to those stars whose motions were irregular. Copernicus found that these heavenly bodies were not mere tramps of the sky, but that they moved in certain

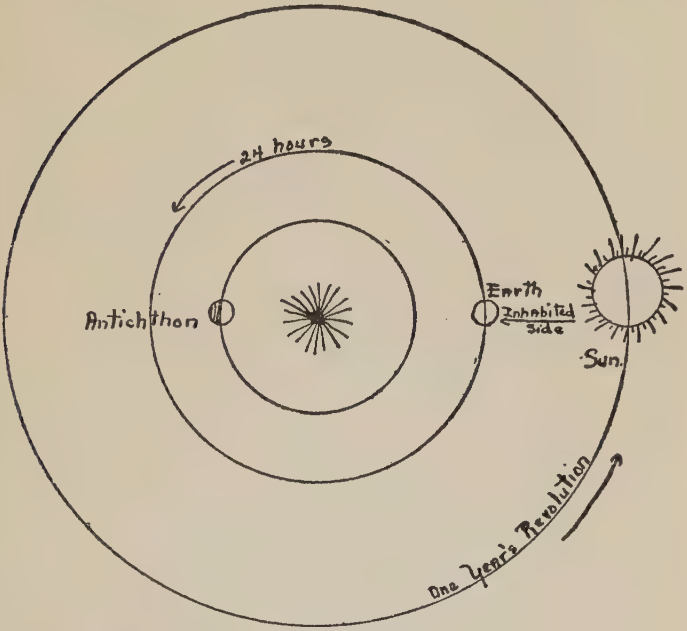


THE SYSTEM OF PHILOLAUS: NIGHT ON EARTH

Only the side turned away from the center is inhabited, consequently the Central Fire and Antichthon are invisible.

regular paths which could be traced and predicted with accuracy.

To return from this historical forecast. It is one of the tragedies in the history of the knowledge of nature that this true sun-centered theory of the universe was discovered only to be lost. Nearly two thousand years before Copernicus, Aristarchus had hit upon the solution of the problem, only to meet the cruel fate of being



THE SYSTEM OF PHILOLAUS TWELVE HOURS LATER: DAY ON EARTH

Earth has made half a revolution and her outer side is now lighted by the sun, which has only moved about half a degree forward in its yearly orbit. Antichthon has also made half a revolution and therefore remains invisible.

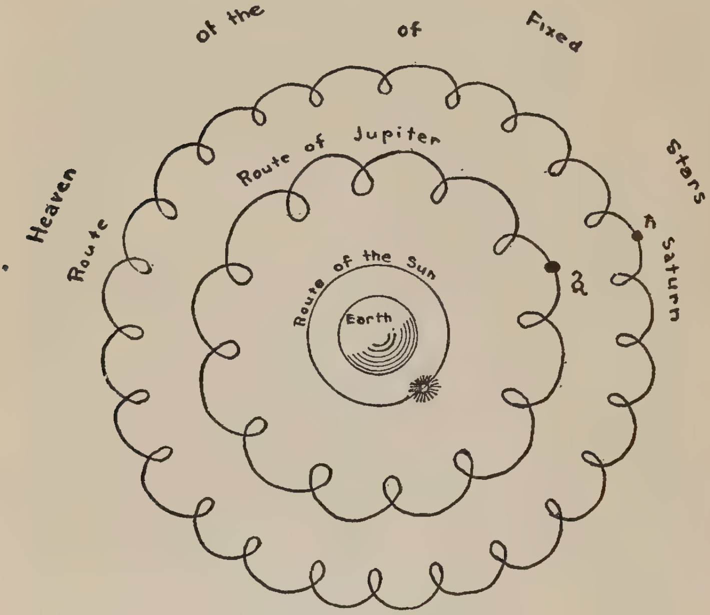
ignored and neglected. The famous mathematician Archimedes mentions this solution but does not accept it, yet to Aristarchus it evidently seemed absurd that the greater body should revolve about the smaller, for he calculated that the sun was at least seven times the size of the earth. This difference was much underestimated, owing to the lack of instruments of precision, but the argument from relative size was valid.

Now Aristarchus' theory of the sun as the center of the planetary movements ran counter to the current beliefs. His fellow citizens of Samoa accused him of impiety, for many, like Plato, believed that the heavenly bodies were a host of immortal intellectual beings. The Aristotelians, too, believed that the motions of celestial bodies might be represented by means of circles and spheres, these being considered the most perfect and most symmetrical figures. Enamored of this fanciful mathematics, Plato's pupil Eudoxus (408-355 B.C.) imagined that the universe is made in a series of concentric spheres, in a scheme which has been compared with an onion made up of a series of successive layers, or a Chinese puzzle consisting of one round box within another down to a central tiny ball, this ball representing the earth. Eudoxus' scheme was this. The outermost sphere was that of the crystal heaven studded with stars. The innermost sphere is solid earth. Between them the sun, moon, and planets are fixed on other spheres, like jewels set in rings. As these rings rolled along, the jewels revolved with them and all sorts of curious motions might thus be accounted for.

§ 12. *Mechanical World Models*

The scheme of Eudoxus, in spite of its poetic fancies, was more or less a successful working model. With its seven and twenty spheres revolving about the earth, he was able to explain some difficult questions. Such were the apparent movements of the planets in their erratic courses, for even the simplest shepherd knew that they did not rise and set with any regularity. By means of his scheme Eudoxus had some success in solving this puzzle. He could explain the apparent movements of Saturn, of Jupiter, and of Mercury; he was fairly close to the movement of Venus; and while he failed entirely in regard to Mars, it must be remembered that the path of Mars in the sky is as eccentric as the flight of a boomerang. By itself the Eudoxian system is not entirely contemptible; it had certain points in its favor. The stars were no longer held to be inhabited by gods, but were considered natural objects; the magical music of the spheres was no longer believed in, but a mechanical explanation of planetary motions was given.

However, in spite of the addition of six new spheres this scheme was not satisfactory. So Hipparchus (*c.* 140 B.C.), of the Island of Rhodes, substituted a system of circles. This remarkable man was later called the father of astronomy, because of his discovery of the precession of the equinoxes due to the erratic movement of the earth's axis, and of his improvement of the astrolabe, an instrument with peep sights like those of a modern rifle. This "well-made copper circle" enabled Hipparchus to make a remarkably accurate map of over one thousand stars. It was Hipparchus who found that the sphere scheme of Eudoxus was too clumsy to work. For it he substituted a system of cycles and epicycles, smaller wheels being added to larger, as in double or multiple gearing.



THE EPICYCLES OF PTOLEMY

Hipparchus is also credited with the invention of the movable eccentric, a circular orbit whose center is not at the center of the earth but off at one side. With this complicated apparatus the astronomer of Rhodes was able to predict eclipses and to work out other astronomical problems so much better than his predecessors that it was almost three centuries before another mechanical world model was originated. The latter was known as the great system of Ptolemy (*c.* 140 A.D.), the astronomer of Alexandria, where the famous university was situated near the mouth of the Nile. The Ptolemaic system was a combination of what had gone before. It rested first upon the great authority of Aristotle, whose notion of the earth-centered universe had gained the day against such astronomical heretics as Aristarchus. Then, too, the orthodox desire for circular motion must be satisfied. This was done by the use of cycles and epicycles and deferents, the last being a device like a smaller wheel revolving upon a larger, thereby completing a complicated scheme needed to represent the apparent motions of the celestial bodies. Finally, the whole must be included within a vast globe, the stellar sphere whose center is the earth.

All these parts of the world machine were assembled, as the name implies, in Ptolemy's famous work *The Great Syntaxis,* a title which suggests that he had put together the views of his predecessors. Thus against the "absurd notion" that the earth is in motion, turning on her axis or moving through space, the argument is brought forward that the earth must be immovable at the center of the universe because the heavy material of which it is made sinks to the center and there remains in globular form without need of support. Likewise the heavenly bodies must be in motion because, being ethereal, it is their nature to revolve eternally in circles.

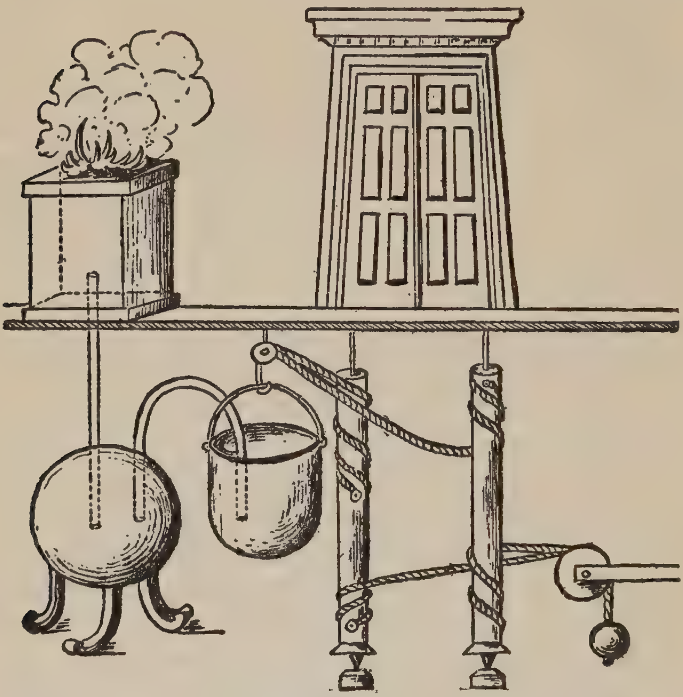
In this last point we recognize the overwhelming influence of Aristotle, for these arguments are but his doctrine of "natural places," it being "in their nature" for heavy bodies to sink to the center and for light bodies to fly off into space. Backed by the authority of Aristotle and working fairly well in representing the movements of the heavenly bodies as they appear to the eye, the Ptolemaic system became the dominant system from ancient to almost modern times. Ptolemy is generally represented as holding in his hand an apparatus used to bring clearly before the eye the motion of the spherical universe with the earth at the center. This instrument, somewhat resembling an egg beater, was believed to be efficient down to the time of Columbus. The high opinion in which Ptolemy and his contrivance were held is expressed by one picture in which the astronomer of Alexandria is shown explaining the use of his armillary sphere to Bœthius, a Roman Senator of the fifth century. Bœthius was the author of a little book called *The Consolation of Philosophy*, a work read down the ages and relished as late as the reign of Queen Elizabeth. It relied upon the learning of the Greeks and taught that the motions of the heavenly bodies were so regular and so dependable that men should not be worried over the petty disturbances of this earthly life. This kind of teaching, of course, appealed to the Church, and by the aid of the Church the system of Ptolemy lasted through the Middle Ages until the dawn of modern science in the Renaissance.

PTOLEMY EXPLAINING THE USE OF THE ARMILLARY SPHERE TO THE ROMAN SENATOR BOETHIUS

§ 13. *Other Mechanical Models*

While the ancients as a whole had the wrong point of view as to the proper center of the universe, the world in which they dwelt offered them many interesting problems. One of these was the size of the earth. This was worked out in a most ingenious way by the superintendent of the famous library at Alexandria. It was Eratosthenes (*c.* 275-195 B.C.) who made a measurement of the globe which came within three or four thousand miles of the correct circumference, and that centuries before the world had been circumnavigated. He proceeded in this way. He heard that in Syene, the most southern city of Egypt, there was a deep well and that on the longest day of the year the sun shone straight to its bottom. Assuming that this well pointed in a perpendicular line to the sun and that another imaginary line could be drawn from Alexandria to the sun, all that was necessary was to get the third side of this assumed triangle. Now the distance between Syene and Alexandria had been measured by the King's surveyors, so by a comparatively simple calculation the circumference of the earth was worked out. It is just as if one should cut a sector from an orange and from the piece of peel and the angle of the sector should measure the size of the orange.

Such was an example of a really scientific piece of work accomplished at Alexandria. Other things were done there which were more of the nature of curiosities and mechanical toys. It may be surprising to learn that the original penny-in-the-slot machine was invented centuries ago by means of simple levers. The temple worshiper would drop a coin in the slot and receive a few drops



DEVICE UTILIZING THE COMPRESSIBILITY OF AIR TO OPEN THE DOORS OF A TEMPLE WHEN THE ALTAR FIRE IS LIT

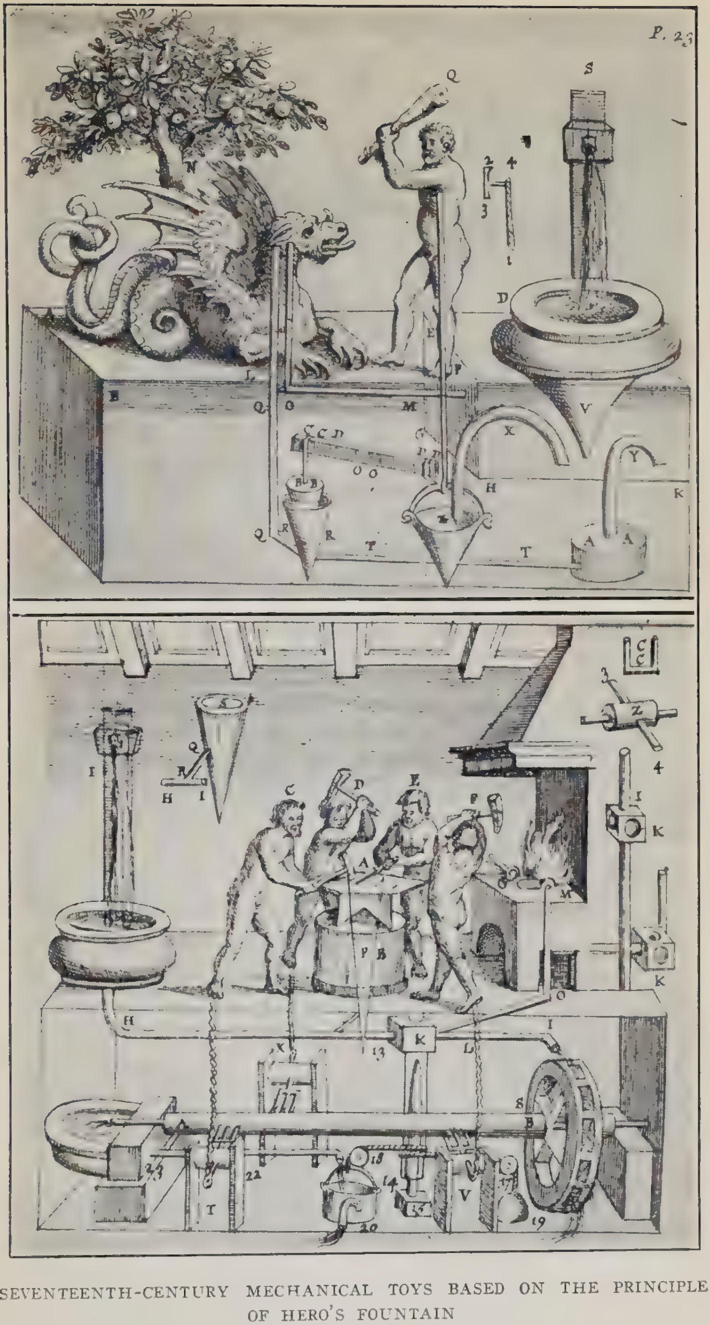
of sacred water from an urn. The principle of the compressibility of air was used in another arrangement connected with temple worship. This device operated by heating air in a closed chamber in such a way that when the altar fire was lighted the temple doors would be opened—much to the astonishment of the worshipers. A mechanical toy which was also invented about this time was the so-called steam engine of Hero (first century A.D.), based on the principle that steam exerts pressure. Unfortunately for Hero's reputation it turns out that this was nothing more than a pair of crooked revolving pipes through which steam was forced. This made these arms revolve much in the fashion of a rotary lawn sprinkler.

This interest in mechanics, however, lay dormant and was not revived until the seventeenth century, the Age of Mechanics. It was then that the notion arose that man is a machine, an assemblage of tubes run by the pressure of air and animal spirits. Hero's only surviving work on pneumatics lent itself to this notion, as can be seen in the illustrations of Hercules slaying the dragon and the blacksmiths hammering on the forge, figures whose action is dependent on the pneumatic device known as Hero's fountain.

More serious work in mechanics had already been accomplished by Archimedes of Syracuse (*c.* 225 B.C.). It was he who uttered the famous words, "Give me a place on which to stand and I will move the earth." By this he meant, as Plutarch explains it, that, given the force, any given weight could be moved, and that if there were another earth, by going to it he could move this one. Besides this complete development of the principle of the lever there is what is known as the principle of Archimedes. This may be stated as follows: A body when entirely surrounded by a fluid is buoyed up by a force equal to the weight of the fluid it displaces. The story connected with this is a curious one. King Hiero of Syracuse had a suspicion that a crown made for him by a certain jeweler was not pure gold, so he asked Archimedes to find out whether the gold was mixed with silver. One day Archimedes stepped into his bath and noticed that as he did so the water flowed over the edge. The story goes that he jumped from his bath and ran naked through the streets shouting, "Eureka—I have found it." What he had found was the principle already mentioned, that the loss of apparent weight of a body submerged in water is equal to the weight of the water displaced. To solve the practical problem for the king, he now took a piece of gold and a piece of silver each weighing the same as the crown. Next he ascertained the volumes of water displaced by the gold, the silver, and the crown in turn, and determined from these the proportions of gold and silver used. Or, according to another authority, he weighed separately the gold, the silver, and the crown while immersed in water, and thus calculated their loss of weight in water. By one or both of these methods Archimedes found that an alloy had been used, much to the satisfaction of the king and the dissatisfaction of the jeweler.

But to go further. One of Archimedes' most ingenious contrivances was the water screw, which was used to drain the holds of ships. Imagine a hollow tube coiled into the form of a corkscrew. All that has to be done to raise water from a lower to a higher level is to put this screw into the water below, keep turning it, and finally the water will pour out above.

These were two valuable discoveries—one as a principle and the other as a contrivance. Antiquity has it also that Archimedes invented other mechanical devices which were so remarkable as to delay the Romans for



SEVENTEENTH-CENTURY MECHANICAL TOYS BASED ON THE PRINCIPLE OF HERO'S FOUNTAIN

three years in their siege of Syracuse. One of these was a series of burning glasses by which, it was said, the Roman galleys of Marcellus were set on fire when they came within bowshot of the walls. Although this episode has been utilized in one of the historical motion pictures, it never actually took place. No burning glasses have ever been made strong enough to set fire to objects at any great distance. But there were other machines invented by Archimedes which probably were effective. Such were the immense cranes worked by pulleys by means of which a few men could let down enormous hooks to become entangled in the cordage of the Roman galleys, and then, with a slow movement of the crank, could lift the ships almost out of the water.

The achievements of Archimedes are like those of the rest of the Greeks of antiquity. They were a mixture of fact and fiction. Starting in a mythical atmosphere, where magic and miracles predominated, they ended in a highly scientific attitude. Yet even with their various machines and contrivances their theories were often wrong, and the uses to which they put their real achievements were often trivial. The unfortunate thing is that many theories which might have had great influence were forgotten. Such was that of Aristarchus that the sun was the center of the universe. Even Archimedes rejected the view of Aristarchus that the fixed stars and the sun are immovable and that the earth revolves in a circular path about the sun, the sun being at the center of this circle. Instead he accepted the view which, as he declares, most astronomers understand, that is, that the universe is a ball of which the center is the middle point of the earth.

Yet in summing up the account we can say that for fully eight hundred years the Greeks had been getting nearer and nearer to the truth, for the era from 300 B.C. to 500 A.D. includes the Alexandrian period, with Euclid's *Elements of Geometry* known to every schoolboy, Eratosthenes who calculated the circumference of the earth, Archimedes, the friend of Eratosthenes, and Appolonius with his conic sections. Now comes a gradual change. As one writer has put it, thirty generations of speculation and much science was followed by thirty generations of speculation with little science. In other words, with the coming of the Romans, of the Dark Ages, and of the Middle Ages, the world in the minds of men became a world of magic. Strange wonders in heaven and earth were recounted by the most serious writers of history. Even in the days of imperial Rome, even when the great pilgrimages of the Church were made centuries later, we find a similar way of looking at the earth as full of portents and terrors. The Age of Magic is then the next period to be taken up.

BOOK II

The Age of Magic

§ 14. *The Vogue of Magic*

The transition from Greek to Roman and Christian times was a twilight zone. The sun of Greek science had set and the darkness of superstition was coming on. What happened was this: The gains made by the really scientific thinkers of Greece were lost for a time. Alongside of the natural philosophers there was always a belief in the supernatural—demons and evil spirits, luck and chance, nymphs and satyrs, all manner of wondrous creatures were held to be real. The scientists tried to get rid of these, but those who were not scientists, from prince to peasant, were convinced of their reality. There were altars to unknown gods, sacrifices to the deities of the underworld, incantations and charms to keep off baleful beings.

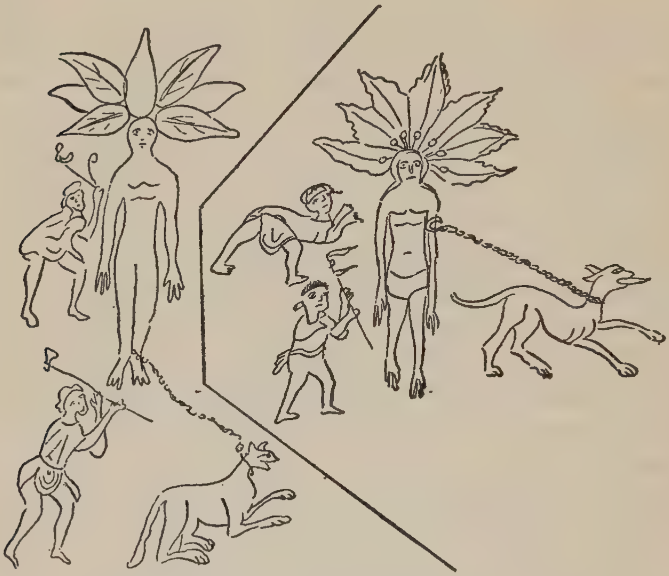
We are apt to think of the Greeks as believers in gods divinely fair and bright. That might be true of the philosophers who thought of nature as the cosmos, a thing of beauty ruled by reason. But this is only half of the picture. There was also a fear of fate and of the dark shadows of the underworld. As time went on other shadows came up from the East. The spread of Rome meant the spread of superstition, for Rome tolerated any kind of strange beliefs and magic practices so long as they did not conflict with the state gods and the state worship. So the Orient once more showed its power; the Magi came from the East and with them magic itself, and all shades of the occult found a refuge in the Imperial City.

We are wont to think of the Romans as entirely practical and hardheaded, but with these qualities went a streak of superstition. The documents show that the foreign magic had an especial appeal. In this way the West obtained its wizards, borrowing them from all over the known world. They were said to come from distant India, burning Africa, and even the antipodes—that paradoxical realm under our feet where men were thought to dwell upside down. All roads led to Rome and many men of many minds traveled those roads. Hence Rome became not only the melting pot of the nations but a market place for all sorts of strange wares. The very science of the day had curious aspects. Magic can be found in the arts, in astronomy, in chemistry, in mathematics, and in medicine, down through the very alphabet of knowledge.

Take a great architect like Vitruvius (first century B.C.), builder of temples and theaters, aqueducts and bridges. His ten books on architecture form not only a storehouse of information but a museum of misinformation. Thus he argues that to choose proper building materials one must consult the gods; this kind of rock or that is not good in itself, but good if it comes under the realm of Jupiter or Neptune or Vulcan.

Take a great physician like Galen (*c.* 130-200 A.D.). He could diagnose disease, tell what was the trouble by symptoms from the pulse, or breathing, or temperature. He was enough of a physiologist to know that certain muscles were controlled by certain sets of nerves. He was so good an anatomist as to be employed as surgeon to the wounded gladiators of his native city. He was so excellent a general practitioner that he finally became medical adviser to the Emperor Marcus Aurelius. Galen was a true follower of Hippocrates, the father of medicine, in considering that disease is due to natural causes and that wise treatment consists in letting nature take its course. But in spite of these excellences there were decided defects in his knowledge and his methods. Owing to the pagan prejudices against human dissection his knowledge of anatomy was deficient. He thought that breathing and pulse beat brought air into the arteries and that the latter were the channels for conducting imaginary "animal spirits" to the brain. In short, Galen shared the deficiencies in knowledge of his time, but owing to his great reputation he perpetuated downright errors and superstitions. Such was the wide-spread belief that the human body contains four humors, corresponding to the four elements, which in turn determine one's temperament. Thus the choleric or angry temperament is due to the preponderance of fire, the phlegmatic to that of water, the sanguine to that of air, the melancholy to that of earth.

Besides humoral medicine Galen helped to perpetuate the doctrine of signaturism. This doctrine held that various plants had certain characteristics or marks which signified their value as remedies. For example, hepatica or liver-wort was used to remove morbid humors due to the liver, while the mandrake, with its roots sometimes fantastically shaped into human form, was a remedy for waning vital powers. It was here particularly that the Orient exercised a magic charm. If a drug came from India or the Spice Islands it was thought more potent than a home-grown remedy. Naturally Galen had hard things to say against the false doctors of his day, charging them with too great a dependence upon occult virtues, incantations, love charms, dream-draughts, and the "characters" of drugs. But the tables were turned and Galen himself was charged by his envious rivals with practicing magic. He talked against Egyptian sorceries and amulets, but he recommended crocodile blood and a bit of peony tied to the wrist for epilepsy. He declared that he saw a boy who wore this root remain free from fits for eight months, but that when it accidentally fell off the fits returned. To prove the power of peony Galen then restored the root and the fits stopped. For



MEDIEVAL CONCEPTIONS OF THE MAGIC MANDRAKE ROOT the purpose of checking his results he took the root off again and the fits went on as before.

This was what was called in those days a medical "experiment." Such experiments led to directions like these: To stop a cough wear the tongue of an eagle as an amulet. To cure a sty in the eye catch flies, cut off their heads, and rub the sty with the rest of their bodies. To extract a tooth in the upper jaw surround it with worms found on the tops of cabbages; for a lower tooth use the worms found on the lower parts of the leaves. We need go no further. Galen's remedies range from the ridiculous to the disgusting, from burned human bones to mouse's dung. To read page after page of these compounds reminds us of the opening scene in "Macbeth," with the witches' broth made up of eye of newt and toe of frog.

However, in passing judgment upon Galen it must be remembered that human superstition has persisted; just as his magical notions went back to the remotest antiquity his superstitions have also lasted until comparatively modern times.

What have been called fossils of the Galenic age were transported to America in the *Mayflower* and Galen's *Art of Physic* was well known in the colonies. The humoral philosophy was definitely referred to by Anne Bradstreet, the earliest poetess of New England. The doctrine of signaturism received a supposed confirmation in native remedies. For example, the kidney beans of the American savages were thought good to strengthen the kidneys, Seneca snake root to cure snake bite, and the red man's concoctions of sarsaparilla and sassafras to purify the blood and drive away bad humors. Thus Galen's ancient art was confirmed by the remedies of the

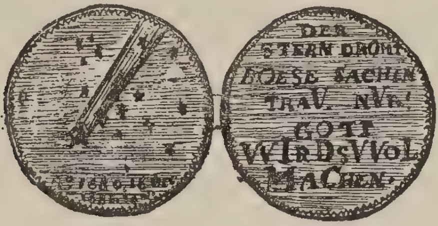
Indian medicine men; in other words, magic medicine in the two hemispheres was on a common level, the level of the aboriginal mind.

It is interesting to trace such primitive medical notions up to the present time. Some rural communities still believe in the Indian or botanical doctors who will prescribe yellow dock for the jaundice or a decoction of toads for eruptions of the skin. The negroes of course still rely on the concoctions of witch doctors, and voodoo remedies are to be found in Louisiana and other parts of the South.

§ 15. *The Vogue of Astrology*

The prevalence of superstition is one measure of the lack of scientific progress. As magic was mixed with medicine, so was it mixed with the other sciences. Astronomy in the false form of astrology is another case, and traces of it can be found to this very day. Farmers' almanacs still contain tables of weather predictions based on the positions of the stars. Patent medicine calendars sometimes carry the diagram of a man in which the different parts of the body are shown to be under the influence of the different constellations, the head being "governed" by the Ram, the neck by the Bull, the arms and shoulders by the Twins, the chest and heart by the Crab. These things are more curious than convincing. But another form of astrology still flourishes—what is known as judicial astrology wherein the stars are judges of man's fate. From the conjunction of the stars at the moment of his birth or at any critical time the astrologer pretends to draw the lines which he must travel. This belief still holds among many. A country circus or a country fair often has its astrological side show where one can have his horoscope cast for a quarter. Even an occasional newspaper carries an astrologer on its staff and character reading can be had for the asking. Here are some recent samples. F. R. S., born July 5, 1909, is told this: "With the moon ruling your natal sign you will be restless and quick to make changes if surroundings do not suit you." Likewise J. B. F., born December 3, 1884, is informed: "For the last year Jupiter had been opposed to your natal sun. You should guard your health when Saturn squares your sun, but as Jupiter at that time also makes a good aspect the bad effects of Saturn will be overcome." J. I. F., born February 6, 1887, is warned as follows: "You have been under the malefic influences of both Uranus and Saturn. These planets produce vibrations which cause illness, sudden changes, and affect the surroundings generally. Judging from the position of Uranus at present your health should gradually improve as well as your affairs."

These horoscopes are taken from a recent American daily paper. One reason for the persistence of these beliefs is that they came over as part of that strange baggage which crossed the wide seas with the emigrants to America. The author of *The Transit of Civilization* offers other ragged remnants of the ancient and complicated science of astrology which survived from the Middle Ages in New England. Such was "A Table of the Astrological Houses of the Heavens" owned by John Winthrop the younger, Governor of Connecticut. By this table "any reasonable artist" may give judgment of the future. There were also the old almanacs which told the farmer to cut his brushwood under certain signs of the zodiac and in the decrease of the moon that it might not grow again, but to cut firewood in the increase of the moon. From these almanacs the colonists learned that comets were agents of mischief, since by drying up the moisture of nature, they caused drought and also excited the air to tempest, thus raising great waves and invading the earth. Others believed they were but a sort of celestial signal hung out to give warning of the imminence of calamities ordained by God. For instance, the blight of 1665, so calamitous to the wheat crop of Massachusetts, was heralded by a great and blazing comet, while the comet of 1680 was called by Increase Mather "Heaven's Alarm to the World." This same comet so frightened the Dutch dwellers on the upper Hudson that they begged the authorities to proclaim a day of fasting and humiliation.



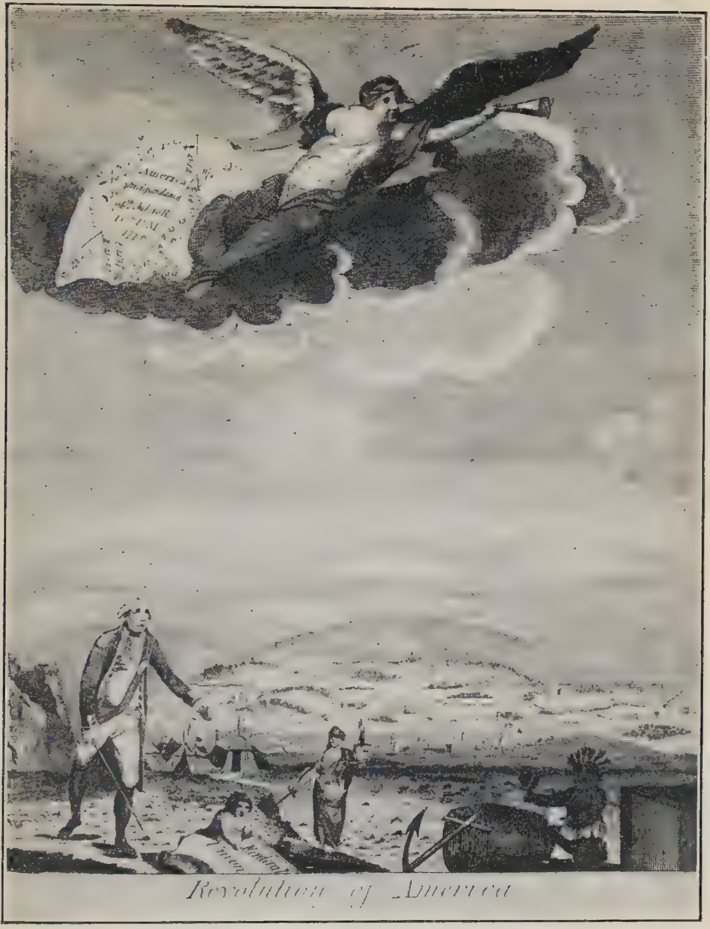
CHARM TO WARD OFF THE EVIL INFLUENCE OF THE COMET OF 1680
Freely translated, the token reads: "The star threatens evil things, only have faith, God will prevail."

These things read like fairy tales and we seem to have returned to primitive times. In truth, such conceits can be traced back for more than thirty centuries. We recall the Chaldeans who cast horoscopes for kings and common people, provided the latter had the money to pay for them. We recall the Egyptians who taught that the different stars had special influences on the various parts of the body. We have now to do with the Romans who were heirs to the past and handed on their beliefs to the future.

The Romans had both natural astrology and judicial astrology. They thought that the heavenly bodies brought wind, rain, and storms, hence the agriculturalist must study the stars. They thought that all men breathe in the emanations of vapors which escape from the heavens, so all must consult the astrologer as an expert on these matters. As one writer put it: The stars follow their orbits in the heavens; but independently of their motion they act upon what passes here below. If you admit that a horse in a gallop, the birds in flying, and men in walking, make the stones jump, or drive little floating particles of dust by the wind of their course, why should you deny that the stars have any effect?

The answer is obvious. If you grant the influence of the celestial bodies, you would be wise to heed them, and people did from high to low. The Roman emperors had their court astrologers and attempted to make a monopoly of the matter. Nero forbade anybody to study the subject lest he should find out when and how the emperor would die. The order was vain, for everybody studied the subject. Thus the Roman satirist Juvenal derided the amateur astrologists, saying: "Avoid meeting with a lady who is always casting up her horoscope. If she only wishes to drive a mile, the hour of departure is taken from her book of astrology. If her eye itches and wants rubbing, she will do nothing till she has run through her conjuring book."

Such was the situation among the pagans. The same conditions held among the Christians. While the Roman emperors forbade divination as treason, the Church councils condemned it as dealing with the devil. But the practice still went on among Christians of all classes. St. Augustine, for example, did not like astrology, yet half believed in it. He tried to throw doubts on horoscopes by citing cases of twins and of the rich man and his



EARLY AMERICAN PRINT DESIGNED TO INDICATE THAT THE DECLARATION OF INDEPENDENCE WAS SIGNED AT THE PROPER ASTROLOGICAL MOMENT

slave who were born at the same moment yet had different destinies. To this the astrologers replied that no two persons are born exactly at the same time because the heavens revolve more rapidly than a potter's wheel. So St. Augustine was forced to grant that their predictions might sometimes be true. But if true, he argued, such success was due to demons who wished to deceive mankind. This, of course, was poor reasoning, for one superstition is bolstered up by another, and thereby the reasoner really proves what he set out to disprove.

The last and perhaps the only real argument used by this learned writer is that the astrologers enslave human free will by predicting a man's destiny in life from the stars. But here the Church father missed a point. Some men want to know the future; if things are going well, they may be willing to let well enough alone, but if things are going ill, they would like to find out whether there is any chance for improvement. So it was that astrology set many minds at ease. In the first place, it promised a great deal. It claimed to give information about human character, health and sickness, prosperity, the fertility of the soil, the state of sea and air, business matters, and journeys. In the next place, astrology said that the sky was a kind of book full of signs each with a meaning. Thus a child born under the constellation Aquarius would become a fisherman, another born under the Balances, a money changer, while a third, born under the Ram, might be as crooked as a ram's horn.

If the sky is a book, all this seems like a primer. It is simple and rather silly. But the astrologers claimed that there was more to it than appeared at first sight. Besides the constellations, each separate planet has its special meaning. *The Book of Wonderful Secrets* tells us that Mars presides over wars and feuds; Venus over love and friendship; Mercury over disease and debts; the Moon over wounds and robberies. Further, there are special planetary influences. Mars is ardent, Venus fruitful, Mercury inconstant, the Moon melancholy. To complete the sacred number of seven planets, Saturn is said to be cold and cheerless, Jupiter temperate, the Sun favorable.

With this key to the mysteries we are ready to cast a horoscope. The first step is to observe what planets and constellations are dominant in the sky at the given moment. The next is to determine what were called "the houses of the sun." First the day was divided into four equal parts: the ascendant of the sun, the middle of the sky, the descending of the sun, and the lower part of the sky. Then these four parts were subdivided into twelve distinct parts which were called the "houses," but it is hard to find out in what house the stars appeared because these houses varied according to the country, the time of the year, the hour of the day and night.

This is the sort of thing found in books like *The Book of Wonderful Secrets* and *The Secret of Secrets*, books which were so popular in the Middle Ages that the Church with all its power could not suppress them. They were as deceptive as the circulars sent out by oil promoters and dishonest stock brokers in modern times. They sounded simple but they were so full of tricks and traps that the astrologer could always escape blame. If his predictions did not turn out to be true, he simply said that the heavens revolved so fast that he could not determine the houses of the sun. It was not his fault, but simply in the nature of things, that events happened as they did. Yet people went on wasting time and money in these fooleries. They were told that their case might be a failure, but that other people had succeeded. There was a case of two boys, one a weaver's son and the other a royal prince of India. Certain sages who happened to be in the weaver's house at the time of the child's birth noticed that his son had a "royal" horoscope. They kept this knowledge to themselves. However, when the boy's parents tried to make him a weaver it was in vain; he gained an education and at last became a royal governor. The other side of the story is easy to guess. The king tried to make his son a ruler, but it did no good; the boy took no interest in anything but mechanics and never ascended the throne. In spite of favorable or unfavorable circumstances each was fated to follow his horoscope.

§ 16. *Astrology as a Learned Superstition*

Such was the popular side of astrology; it remains to study the sources and the reasons that were put forward to uphold it as a science. Ancient astrology satisfied a craving for the marvelous and at the same time it sought for vindication as a rational scheme. Recourse was had therefore to the philosophers. The four elements of Empedocles with their proper qualities were connected with the stars, and the latter were thought to be not signs only, but causes of immoderate heat or cold, drought or moisture. The mystic numbers of Pythagoras also lent themselves to the magical study of the stars, while the notion of Plato as to the planetary gods and as to the stars being inhabited by souls was in itself astrological. But above all, Aristotle's cosmology formed a sort of interlocking system in which the circular motions of the heavenly bodies were transmitted to the earth, especially to the cyclic processes of growth and decay seen in man, animal, and plant. Then, too, this great authority had put forward his doctrine of the fifth essence, an addition to those of the four elements. This assumed that the substance of the stars was of a nobler order than terrestrial things—the earth, as he declares, being "bound up in some necessary way with the local motions of the heavens, so that all power that resides in this world is governed by that above."

Thus astrology became what has been called a learned superstition. The Greeks had probably derived their earliest notions of it from the Chaldeans, who were more diviners and soothsayers than they were astronomers. But the final touch of authority was given by Ptolemy of Alexandria, who pointed to the influence of the moon upon the ocean and of the sun upon the seasons and asserted that other heavenly bodies act in a similar manner. So he adds, astrology can be divided in two main parts: first, that which deals with general predictions regarding war, pestilence, earthquakes, floods, storms, hot and cold weather, and fertility; and second, that which deals with predictions regarding the individual, his parents, brothers, length of life, health, riches, profession, marriage, children, and friends. For the latter class of predictions the planets are divided into the good, like Jupiter and Venus, and the bad, like Saturn and Mars, while Mercury varies his nature as he stands near a good or bad neighbor.

All this, together with the signs of the zodiac, the planets and the constellations, and the twelve celestial "houses," made of astrology a learned system. Its success was in part rendered possible by the famous Stoics who traveled about in their philosophers' cloaks and taught their doctrines in the forums and market places of the Roman world. Stoicism taught that man should grimly endure whatever befalls him. Consequently astronomical predictions were considered anything but useless, on the ground that "prophecy is naturally welcome when the thing foreseen is pleasurable; when, on the other hand, the thing foreseen is painful its prediction prepares the soul to bear misfortune with equanimity." The Stoic practice was linked with the Stoic theory that man is part and parcel of the universe and that whatever happens in the higher regions has its effects upon the lower.

This general proposition was seized upon by those who did not believe in such a universal fatalism. One critic asked this question: "What have the names given to the constellations of the zodiac to do with the actions and habits of man? What possible connection can exist between the celestial Lion and the warrior's bravery or between the Virgin and a white skin? Can anything be more absurd than to make of the Bull a feminine sign?" The same critic further asks: "Were all the barbarians killed at Marathon born under the arrow of Sagittarius, and all the heroes drowned at Salamis under the sign of the Water Carrier?"

But in spite of the satirists astrology spread throughout the Roman world. As a learned superstition it had the backing of the greatest astronomer of antiquity, Ptolemy of Alexandria. As magic it was consulted by emperors from Augustus to Alexander Severus. However, the early Church attacked it as a remnant of paganism, and the Church Fathers like St. Augustine attempted to overthrow it by means of such sophisticated arguments as that it was only one of the practices by which the host of fallen angels attempted to cheat mankind.

Yet it was not so much through the Church as through the decline of learning during the Dark Ages that astrology suffered a real but temporary eclipse. With the revival of Greek learning in the twelfth century, it again came into fashion. Through the Arabs Aristotle was translated into Latin, and there took place a certain compromise between the Greek cosmology and "judicial" astrology or the prediction of the future according to the configurations of the stars at birth. Thus the star of the Magi or Wise Men of the East at the nativity of Christ could not be deprived of the significance given it by the astrologers. Still the Church hesitated to utilize this prediction, and it is conjectured that one reason why the English monk Roger Bacon was imprisoned was because he undertook to cast the horoscope of Christ himself. Nevertheless the "diabolic art" gradually became respectable, and from the thirteenth century to the sixteenth several Italian universities, like Padua and Milan, had chairs of astrology, and even during the Renaissance we find Galileo casting horoscopes for the Medici family. Court poets like Petrarch may have derided the astrologers for turning free men into "slaves of the insensible stellar spheres," but despite satire by the critics and fraud by the astrologers themselves the art continued to have its princely and royal patrons. Rulers were even known to bribe astrologers to cast unfavorable horoscopes against rival rulers, and no court astronomer until the time of Kepler had the hardihood to decry the usefulness of astrology, for refutation was impossible until the new astronomy came in and swept away the systems of Aristotle and Ptolemy.

Until that time, then, all classes believed in the celestial control of mundane affairs. Royal astrologers were attached to the courts not only of Spain and Portugal but of England and France. Queen Elizabeth consulted John Dee, and Louis XI had this curious adventure. He sent for a certain astrologer who had prophesied the death of one of the king's friends. He scolded him for this, and then asked him: "You, who know everything, when will *you* die?" The astrologer replied: "Sire, three days before Your Majesty." The monarch was so superstitious that he believed him, and we can be sure that the prophet was well looked after for the rest of his life.

Such is one of the tales of an astrologer to the Very Christian King of France from *The Book of Unheard-of Curiosities*. The whole thing seems futile except for this, that in many cases good came from evil and some truth from a foundation of falsehood. What Catherine de Medici did is an instance of this. She had a tower built in Paris and kept an astrologer watching at the top; later this became an astronomical observatory, surmounted by a celestial sphere and a sundial. The same thing happened in other places. Galileo was astrologer to the Grand Duke of Tuscany, yet one thing he did with his telescope was to sweep away the notion that the celestial vault was a book whose stars, like the letters of an occult alphabet, foretold the fate of empires. A similar thing happened with Tycho Brahe, astronomer royal of Denmark. His monarch had built for him a magnificent observatory to study the stars and learn their meaning, but Tycho used it chiefly to make exact observations and measurements.

And so the double game went on, for the position of these men was most curious. They were hired to cast horoscopes, to tell what would happen to the new-born prince or princess, to advise the king on war and peace, on statecraft and diplomacy. This was their task for which they drew pay, astronomy proper being merely a side issue. But it is doubtful if they would have made many of their scientific discoveries if the rulers had not supplied them with funds to build observatories, to construct astrolabes, telescopes, sextants, quadrants, and other instruments of precision. In a word, then, like so many of the advances in human knowledge, that which began as magic ended as a useful instrument in the study of the order of nature.

§ 17. *Alchemy*

As astrology was a learned superstition connected with astronomy, so was alchemy an occult science connected with chemistry. Like astrology it was as old as the dawn of history, being allied with the earliest worship of the heavenly bodies. Common language has traces of this origin in the attributes of the metals—gold corresponding to the sun, silver to the moon, iron to Mars, and mercury to the planet of that name. The mythological history of alchemy is most fantastic. Tradition has it that Egypt was the birthplace of this "secret art of chemistry." One account declares that Hermes, the prophet and king of Egypt after the flood of Noah, obtained it by revelation of an angel of God. From the cult of the mythical Hermes, who is identified with the Egyptian god Thoth, we obtain phrases like "the hermetic art" and "hermetically sealed" as when a vessel is rendered air tight by heat. In the usual representations Hermes as an alchemist is pictured as a magician of fire, for the fabulous bird Phœnix is shown rising from the flames near by. The mythical Hermes also wears the Arabian turban, and this symbolism points to the fact that it was the Arabs who introduced the very word alchemy into medieval Europe, just as they did alembics and the so-called "Moors' heads" and "Moors' noses," the popular names for various chemical retorts and the like.

The word alchemy, though of Arabian origin, has been traced further back to the Greek word *chemi*, signifying black and thus connected with Egypt and the black soil of the Nile valley. At any rate the earliest chemical manuscripts we possess are two papyri from the Egyptian city of Thebes. Among other things these documents contain directions for imitating gold and silver by means of yellow and white alloys of copper. This was taken to be a case of the transmutation of base metals to noble and may be connected with the medieval fancy that the golden fleece which Jason and the Argonauts went in search of was an ancient papyrus containing the secret of making gold.

ALCHEMIST HERMETICALLY SEALING A GLASS VESSEL

The medieval alchemists added to this confusion by taking the fabulous philosopher's stone, which was both a magic stone of longevity and a magic powder of transmutation, and making it respectable by arguments from the Bible. If the patriarchs like Methuselah, before the Flood, lived over nine hundred years, "how was that possible," it was asked, "without a knowledge of the philosopher's stone?" When Moses took the golden calf and reduced it to powder and "strewed it upon the waters," "how could he have done so without a knowledge of the conversion of metals?"

The wisdom of Egypt was another belief derived from the Bible and relying upon this the medievals concocted some curious notions. Thus the legendary Egyptian god Hermes Trismegistus, or thrice greatest, is made responsible not only for the rediscovery of all the arts and sciences after the Deluge, but for alchemy itself. Alchemy is not only a science but a material object, and as such is defined by one writer as that substance which joins the less precious bodies which are compounded from one original matter and by this same natural union converts them to the higher type.

This belief of the alchemists in one primordial matter naturally links itself with the belief in the four elements. Here recourse is again had to Aristotle, "the foundation of all wisdom." By him each element was supposed to be possessed of two qualities. Fire is hot and dry; air is hot and wet; water is cold and wet; earth is cold and dry. Since the relative proportion of these qualities determined the specific character of the elements, the transmutation of the elements is rendered logical. For example, if the dryness of fire is overcome by the moisture of water, air is produced; if the heat of air is overcome by the coolness of earth, water is formed; if the moisture of water is overcome by the dryness of fire, earth results.

These doctrines of Aristotle were brought into medieval Europe by the Arabian translators of the lost manuscripts of the master, thus rendering alchemy another learned superstition. Christian scholars like Roger Bacon acquired these doctrines in the twelfth century, and by the fourteenth the cult of alchemy became a veritable religion. Its articles of faith have been enumerated as belief in transmutation, in the philosopher's stone, in the universal medicine, and in the elixir of life. The chief of these appears to have been the philosopher's stone, variously called the "grand magistery" and the "quintessence." The last name, the fifth essence, is reminiscent of Aristotle's fifth element, the ethereal substance of which the heavenly bodies consist. "The stone," as it was popularly called, was generally described as a red powder having supernatural powers. One grain of it could change lead into gold, or cure disease, or restore youth, or prolong life. Extravagant claims indeed were then made for this philosophical powder, and only occasionally did men make qualifications as to its power, one admitting that as the elixir of youth it prolonged life only "until the supreme hour fixed by the king of heaven," another pointing out that as a universal solvent no vessel could contain it.

In general, caution and reason were not qualities of the alchemists, and in the search for the philosopher's stone extravagant opinions were held even by the highest. Pope John XXII had a laboratory in his palace at Avignon for the purpose of practicing the art of transmutation; so did the Emperor Rudolph II with his title of the "Hermes of Germany." It is claimed that nearly every court in Europe had its court alchemists as it had its poet laureate and its court fools, and we can well believe that the alchemists had both fanciful qualities of the former and the foolish qualities of the latter, when we read what Robert Boyle said of them in his *Sceptical Chemist.* He compared them in their searches after truth with "Solomon's fleet which brought home not only gold and silver and ivory but apes and peacocks too. . . . So the Hermetic philosophers present us with theories which are either like peacock feathers, making a great show but neither solid nor useful; or like apes, having some appearance of being rational, but blemished with some absurdity or other which makes them appear ridiculous."

With Robert Boyle, a founder of the Royal Society of England, there begins in 1661 the first really critical attack on the alchemists. A century later, just prior to the French Revolution, Lavoisier succeeded in expelling the alchemists from the company of chemists, just as Copernicus with his discoveries had expelled the astrologers from the company of the astronomers. However, in looking back, it must be granted that the alchemists accomplished something, for the secret art of Alexandria, emerging from the Egyptian mysteries and claiming to have an occult connection with the stars, was taken over by the Arabs who rendered certain services in the discovery of useful processes and substances. Such were the ordinary chemical processes, like distillation, sublimation, calcination, filtration; and substances like carbonate of soda, pearlash, sal-ammoniac, alum, copperas, borax, silver nitrate, cinnabar, and corrosive sublimate.

When the alchemists did make these contributions, it was more or less by chance, in connection with their futile searches after the philosopher's stone, which would transmute base metals into noble, assure long life, perpetuate youth and prosperity, and as a panacea, or universal remedy, cure all ills which flesh is heir to. So from the time of Harun-al-Rashid, the princely night prowler of Bagdad described in the *Arabian Nights,* to the time of the building of the Alhambra in Spain, the alchemists worked away on these vain schemes, chasing the rainbows of wealth and health and happiness.

Christian Europe, inspired by the schools of Bagdad and Cordova, took up this chase, and there appeared a host of treatises like *The Key of Wisdom, The Secret Book on the Philosopher's Stone,* and *The Treasure of Treasures.* One of the best known of these treatises was entitled *On the Secret Work of Nature.* It was written by the English monk Roger Bacon, the reputed discoverer of gunpowder. The composition of this mixture "which will produce a thundering noise and a bright flash" is given in a secret cipher in the form of an anagram. The story goes that Bacon was blown out of his cell when his mixture worked, but it is probable that his instructions for "refining saltpeter" were simply a revival of a dangerous discovery already made by the Chinese. It is not meant here that Roger Bacon made false claims, for, on the basis of recently recovered manuscripts he has been credited with the discovery of both the microscope and the telescope, but in keeping his alchemical accounts secret he did simply what others were forced to do. Practically all the medieval alchemists sought the protection of king or cloister to carry on what came to be known as the black art, or the art of Satan. Thus Vincent of Beauvais, tutor of the children of Louis IX, was suspected of calling on the spirits in his alchemical experiments, and the people used to prowl about his laboratory to catch a glimpse of his glowing furnaces in the palace yard. At about the same time the rumor was rife that the alchemist Raymond Lull would have been prosecuted by the Inquisition if he had not attempted to make magic money in the Tower of London for King Edward III in order to carry on war against the infidels. As a matter of fact kings did employ these wonder-workers. Henry VI allowed certain persons to practice the "divine art" of transforming into fine gold the commonest of metals. But this was about as illusory a way of paying a country's debts as is overworking the printing press and issuing millions of paper money, as Queen Elizabeth discovered from the vain promises of the alchemist Lannoy to produce fifty thousand marks of pure gold yearly "on certain conditions." Neverthless, even with royal protection the alchemists were in danger. If they did not produce results they were sometimes put to torture. So resort was often had to trickery. One scheme was to put a double bottom to a crucible; the one below was real, the one above was wax, painted to look like lead; conceal some real gold between the two bottoms, start the fire, pronounce some magical formulas, and the wax will melt and the gold appear. Or a fagot containing silver filings and plugged with wax is placed upon the coals, or a hollow cane filled with the precious metal is used as a poker, all with similar results to deceive the credulous.

If base metals could apparently be turned into more noble, there was danger that those who knew this black art would fill the country with false money; hence laws were passed in England and elsewhere against such practices. An English statute of 1403 declares that "the craft of multiplying gold" was a felony. Still the people believed that the alchemists were secretly keeping up the practice of their magic. They were thought to be fabulously rich as well as fabulously old. Consequently the public kept on buying their mysterious mixtures, which were thought to prolong life, cure diseases, or render them invulnerable, a grain or so of the philosopher's stone being more potent than would be all our patent medicines put together. The alchemists were reputed to possess perpetual health and colossal wealth. They therefore tried to create a monopoly of their magic by casting an air of mystery about their processes. They did know about certain useful drugs, such as bismuth and liver of sulphur, but they purposely confused their formulas with so many strange words and mysterious expressions that only a fellow alchemist could understand them.

The final impression left on our minds may be represented by the conventional picture of the alchemist's den, a dark room cluttered up with skulls and crossbones, black cats and stuffed owls; its walls are adorned with astrological figures and a general air of hocus-pocus hangs about the place. Naturally all this lent itself to ridicule, and the alchemists, as a company of educated charlatans, were ranked with the conjurors and "cunning" men from the time of Chaucer in his "Canon Yeoman's Tale" to the time of Ben Jonson in his biting satire *The Alchemist*.

§ 18. *Unnatural History*

In the Middle Ages people were really playing the old game of twenty questions. They asked: "Is it animal, vegetable, mineral, or human?"—and the wise men gave quaint answers. Some of these we have already heard in the teachings of the physicians and the alchemists, but others went further. If this or that vegetable or mineral has a good or bad effect on humans, may not this or that animal have much to do with the welfare of men? It was a natural question, but it was answered by what might be called unnatural history.

We turn then to *The Book of Unheard-of Curiosities,* concerning beasts. Such bestiaries or books of animal anecdotes generally started with some references to astrology. As the stars were humanized, so were the animals; as they were thought to possess souls, so were the beasts; as the heavenly bodies had messages to convey, so did earthly creatures. In short, "nature faking," which began with objects above, did not stop with objects below. All living creatures were given motives and morals and were even said to have feelings of worship. A certain insect stood up and folded its front legs together. It was therefore called the praying mantis. And even back in the first century we find Pliny the Elder, the author of a famous natural history, representing elephants as worshiping the stars, the lion as having a sense of gratitude, and the crocodile as opening its jaws to have its teeth picked by a bird out of pure friendship.

Pliny perished in the eruption of Mount Vesuvius which destroyed Pompeii, but his fairy tales lived on. The men of the Middle Ages were especially fond of these tales and added new ones in their bestiaries. The belief in sympathetic medicine was brought in. Swallows cure their young with swallow-wort; so may men. The hawk can gaze at the sun without hurting his eyes, therefore doctors should prescribe hawk-weed for sore eyes. By watching the beasts men can learn not only about health-giving drugs, but even beneficial surgical operations. In the days when bleeding was believed in it was said that this remedy was discovered by the hippopotamus, which cut open its veins with sharp reeds and stopped too great a flow of blood by plastering the wound with mud.

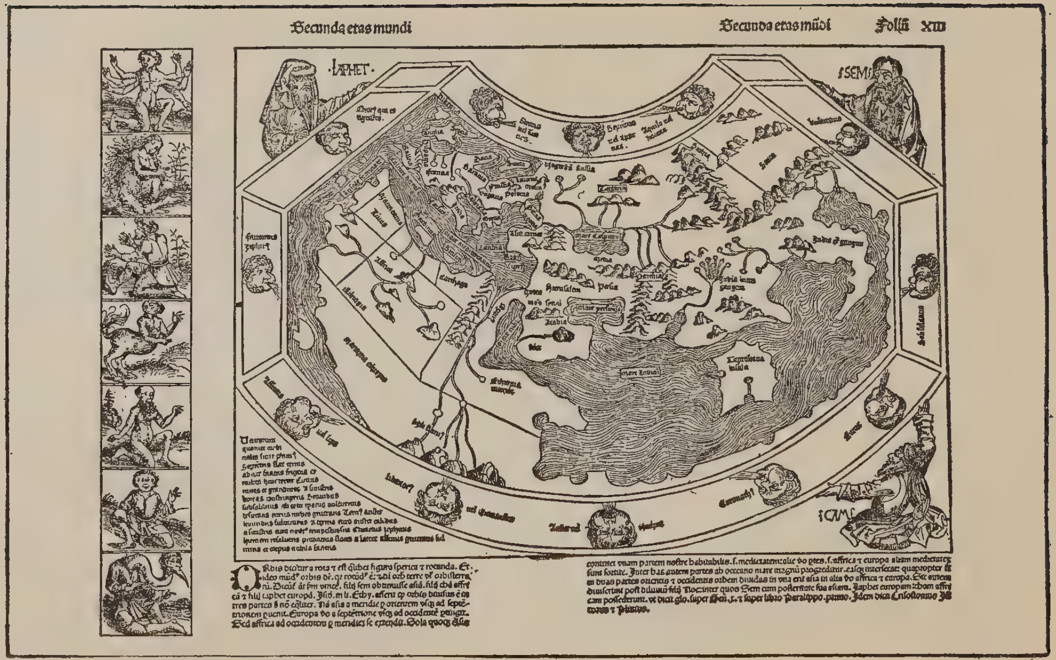
These stories were evidently made up to fit the facts. They were afterthoughts and not real discoveries, as so many were wont to believe. It was by this kind of reasoning that men attributed not only sagacity to animals but also other human traits, bad as well as good. The worshipful elephant is sometimes jealous; he knows men hunt him for his tusks; consequently, when these drop off he buries them. The faithful dog is often spiteful; if you keep watching him he will not go and pluck the herb by which he cures himself of snake bites.

Most of these stories were derived from the ancients. Besides Pliny with his *Natural History* there was Plutarch with his *Essays*. These included strange stories of the cleverness and craftiness of animals. He tells about fish who rescue their kind by biting through the line or by dragging them by the tail out of the net. He mentions sentinel cranes who stand on one foot and hold a stone in the other in order to wake themselves up. In case they fall asleep they will relax the latter claw and let the stone drop, and the noise will serve as an alarm. The choicest tale of the time is that from Ælian's *Nature of Animals*. Eagles, says this author, drop tortoises on rocks to break open their shells, and the bald-headed poet Æschylus met his death by having his pate thus mistaken for a smooth round stone.

Stories like these became the regular stock in trade of the "nature fakirs." Two centuries after Pliny the pagan writer Celsus mentions the elephant keeping his oath, refers to the knowledge of medicines and poisons possessed by other beasts, and adds stories of the assemblies of animals where they discussed the welfare of their kind. As time goes on these tales are embellished. A certain Ætius tells of a partridge which was much disturbed when poison was being prepared in the house; of a pet eagle which would attack any one who even plotted to poison another; of a peacock which would upset the vessel containing a dangerous potion. The Christian writers picked up these and similar stories. St. Augustine tells about an adder resisting the incantations of its charmer by putting one ear to the ground and stopping the other with the end of its tail.

When the medievals got hold of these tales they did not lose in the telling. The Englishman Alexander Neckam explains how the weasel, wounded by a venomous animal, at once searches for some herb or antidote. The reason given is that "educated by nature, it knows the virtues of herbs, although it has neither studied medicine at Salerno nor been drilled in the schools at Montpellier." Evidently a college education had no value for this animal, for nothing could be sharper than a weasel.

Such stories could be cited by the dozen. They simply showed how false observation and pleasing fiction can turn natural history into unnatural history. When we read modern animal anecdotes and jungle stories we do not confuse them with the findings of science, but the ancients and medievals did. They call their bestiaries "Mirrors of Nature," but the mirrors they held up to nature distorted the image, and when moral reflections were added to animal anecdotes the limit of absurdity was reached. There was Bartholomew of England who wrote a book on *The Properties of Things* for the benefit of young scholars and the general reader. He gives amusing anecdotes of cats and dogs which perhaps did something to prevent cruelty to animals in a cruel age. If animals have feelings like ours, we should not hurt them in any way. There is, for example, the whale which cherishes its young with wondrous love; when they are stranded on shoals it frees them by spouting water over them. But Bartholomew goes even further. He thinks that all kinds of animals were created for man's good. Even fleas are useful in leading man to recognize his own infirmity and thus invoke the name of God.



Courtesy of The New International Encyclopædia.

NUREMBURG MAP OF 1493 SHOWING MONSTROUS HUMAN BEINGS

§ 19. *Travelers' Tales*

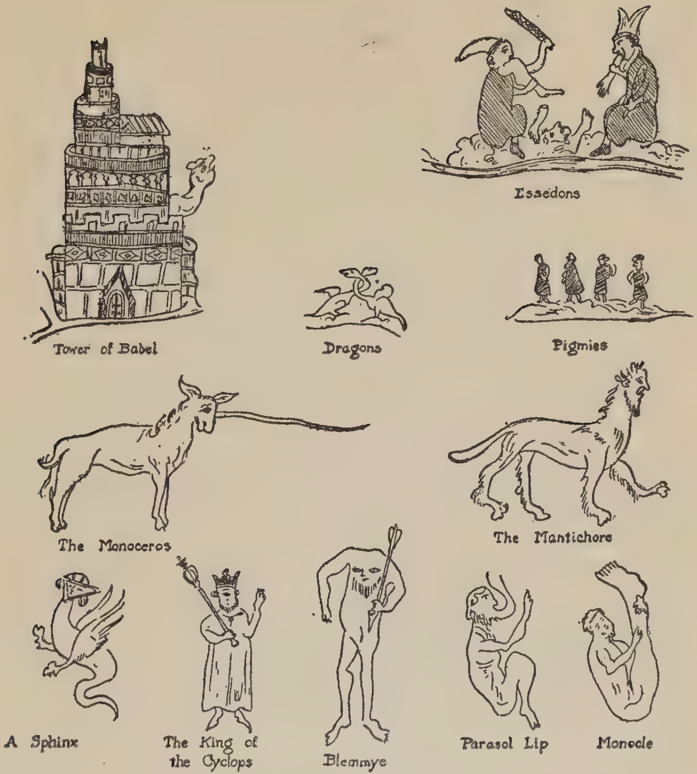
From Pliny, the father of "nature fakirs," to Bartholomew of England was over a thousand years. Meanwhile the Crusades came and added fresh material to the marvelous, while the absurd beliefs of explorers brought in a new note, the terror of nature. This note lasted up to the time of Shakespeare, who spoke of moving accidents by flood and field, and of the cannibals that each other eat, and of men whose heads do grow beneath their shoulders.

The falsification of facts now reached its height. The so-called "mirrors of nature" were like those mirrors seen in a "mystic maze" which distort people's features into horrible grimaces and make everything unnatural. Fancy ran riot and there was nothing too hard to swallow. There were queer distortions in every direction. The legends of Alexander the Great, the monkish chronicles of the Crusades, the travels of Marco Polo—who writes at times like Baron Munchausen—all these were built up into a pyramid of the impossible. In the Alexander story we have pictures with titles such as these: "How Alexander Fought the Dragons and a Species of Beast Called Scorpion"; "How Alexander Fought the Dragons with Sheeps' Horns upon Their Foreheads"; "How Alexander Engaged in Combat with Men Having Horses' Heads and Vomiting Smoke from Their

Mouths"; "How Alexander Lowered Himself into the Sea in a Glass Barrel."

From prehistoric monsters to prehistoric submarines nothing was too impossible to believe in relation to Alexander the Great. All these titles are from a single manuscript. But there were others like Jules Verne with his *Mysterious Island* and *Twenty Thousand Leagues Under the Sea*. These were the monkish chroniclers, members of the various orders who were seized with a passion for travel or set out with a mission to convert the world. Unfortunately for the advancement of learning, they were astrologers, alchemists, and theologians first and natural scientists afterwards. They were good men but not good observers. For example, there is a monkish description of the ostrich which has "the head of a goose, the body of a crane, the feet of a calf; it eats iron." This reminds one of the Roman soldier's account of Hannibal's elephants as "monstrous oxen with tails at both ends."

The description of the ostrich is a mixture of truth and falsehood. Other creatures are similarly distorted. Some traveler evidently saw the one-horned rhinoceros; as drawn by the monkish artist it becomes the monoceros, a quadruped with the long twisted horn of the narwhal or sea-unicorn. Thus observation and imagination were blended and endless combinations of fabulous monsters arose. We are familiar with dragons as made up of reptiles with the wings of birds, of gargoyles as a cross between crocodiles and dogs. But for fancy run riot we must go to such a map of the world as that of Richard of Haldingham in Hereford Cathedral. This great wall map contains the regulation pictures, Biblical and classi-



FIGURES FROM THE HEREFORD MAP

cal. Such are grotesque representations of the Garden of Eden, Noah's Ark, and the Tower of Babel, of the King of the Cyclops, the Minotaur, and the Pigmies. But besides these it contains some novelties. Near the Tower of Babel is the land of the Essedons, "whose custom it is to sing at the funerals of their parents and tear their corpses with their teeth." Next, in India, lives the Mantichore, "who has a triple range of teeth, the face of a man, the body of a lion, the tail of a scorpion; its voice is a whistle." North of the Ganges dwell the Monocles "who have only one leg; when they wish to protect themselves from the heat of the sun, they make a shadow with the sole of their foot, which is very large." Next come the Blemmyes, "who had their mouth and eyes in their chests." Finally, the legend runs: "The customs of the people of the interior of Scythia are somewhat wild; they inhabit caves; they drink the blood of the slain by sucking their wounds."

Perhaps such monkish descriptions satisfied the dramatic instinct or took the place of novels. The cannibalistic Essedons read like Shakespeare's Anthropophagi, and the Blemmyes like his "men with heads beneath their shoulders." The other monsters remind us of *Gulliver's Travels* to the land of the Brobdingnags or giants and the Hounyhyms or humanized horses. But this explanation is perhaps forced. Fiction was not distinguished from fact, for the medieval mind was nothing if not literal. People who swallowed astrology and alchemy were not likely to strain at such travelers' tales as these.

The medieval mind relished not only fiction to please but fiction to frighten. Yet it seems that the thing was carried too far. There were not many who could be persuaded to go off on these terrible adventures. And yet there were a few who were impelled by two motives. These motives were the glory of God and the love of gain. The former affected the pious Crusaders and the missionary orders of monks. The early Crusades were not luxurious journeys or personally conducted tours.

They were arduous and dangerous. Many perished by the way, if not from dragons and demons, then from hardship and disease. And all the time the dark cloud of fancied terror frightened the followers of Peter the Hermit or whoever might inspire the great crowds which trod the pilgrim's way. Later the Crusades were better organized and pilgrimages became safer. Warriors like Richard the Lion-Heart and his knights protected the travelers. The roads were mapped out and caravansaries and strongholds dotted the eastward way from England to the Holy Sepulchre.

But those who traveled farther east than Jerusalem deserve the highest credit. Such was the Gray Friar John de Plano Carpini, sent by the Pope to convert a Tartar chief. Next to this first Christian to penetrate into the wild lands beyond the Caspian Sea was the Franciscan monk sent to Mongolia. It was such missionaries who blazed the way for the commercial travelers and whose accounts were assembled in the book of travels of the English knight Sir John Mandeville, who was supposed to have drawn upon the monkish chronicles, combined them with Alexander's *Marvels of India*, and concocted a volume which delighted his readers but did not add much to science. In his travels the famous but fabulous author finds wonders such as these:

> There is the land of the Great Khan, a fair land and plenteous of goods, the King thereof possesses fourteen thousand elephants or more that he maketh for to be brought up by all his towns. There be also in that country a kind of snails that be so great, that many persons may lodge them in their shells, as men would do in a little house. After this country men go by many isles by sea unto an isle that men called

> Milke, full of cursed people who drink gladliest man's blood. From that isle, in going by sea toward the south, is another great isle that is called Dondun. In that isle be folk of diverse kinds, so that the father eateth the son, the son the father, the husband the wife, and the wife the husband. In one of the nearby isles be folk of great stature, as giants. And they be hideous for to look upon. And they have but one eye, and that is in the middle of the front. And they eat nothing but raw flesh and raw fish. And in another isle be folk of foul fashion and shape that have the lip above the mouth so great, that when they sleep in the sun they cover all the face with that lip. And in another isle be folk that have horses' feet. And they be strong and mighty, and swift runners; for they take wild beasts with running, and eat them. In the kingdom Abchaz which is in subjugation to the Khan there is a great marvel, a land called Hanyson; it is all covered with darkness, without any brightness or light; so that no man may see nor hear, nor no man dare enter into it. And they say that the darkness befell by miracle of God. For a cursed emperor of Persia, that was called Saures, pursued all Christian men to destroy them and to compel them to make sacrifice to his idols. And as a punishment for this anon a great thick cloud came and covered the emperor and all his host. And so they endure in that manner and so shall they evermore abide in that darkness till the day of doom, by the miracle of God.

Mandeville goes on further to describe the royal estate of Prester John, a mythical rival in magnificence to the Great Khan:

> In the sea near the isle of Prester John are many places in which be great rocks or stones of the adamant, that of its proper nature draweth iron to itself. And therefore there pass no ships that have either bonds or nails of iron within them.

> And if there do, anon the rocks of the adamants draw them to them, that never they may go thence. In this country also is the sea that men call the Gravelly Sea, that is all gravel and sand, without any drop of water, and it ebbeth and floweth in great waves as other seas do, and it is never still. Near this Gravelly Sea is a desert in which be many wild men, that be hideous to look on; for they be horned, and they speak nought, but they grunt, as pigs.

But enough of the marvels of Sir John Mandeville.

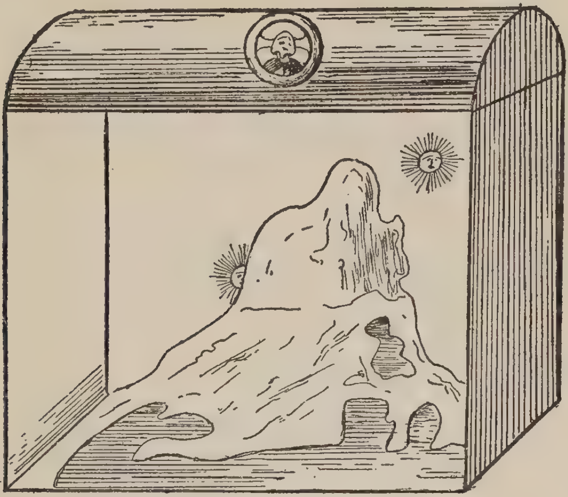
Besides this gentleman adventurer was the famous merchant adventurer Marco Polo. Starting from Venice he went through Tartary and Mongolia and even reached Cathay or China. For twenty years he held an important post at the court of the Great Khan, that mysterious monarch whose country was the goal of Columbus' first voyage. According to Marco Polo's own account, he made and lost several fortunes. As for his knowledge we can hardly say that he was much more than a medieval romancer, for his map of the world is a curious thing and his stories well-nigh incredible. He asserts that he had not seen Paradise but that he had seen the Ark of Noah resting on Mount Ararat. Such were the tales of the travelers.

§ 20. *Medieval Geography*

The habit of believing in the marvelous hung on. We have traced it in astrology, alchemy, natural history, and travelers' tales. Now we must take up the earth itself and find out the fantastic shapes which the medieval mind gave it. There is a curious contrast here. With the Greeks the larger the earth was found to be the more scientific grew their view of it. With the medievals the larger the earth, the more magical it seemed to them. Distance lent enchantment to their view. It also led to distortion.

The legendary worlds of the Middle Ages were most strange. The Venerable Bede at the time of Alfred the Great declared that "the earth is an element placed in the middle of the world as the yolk is in the middle of an egg; around it is the water, like the white surrounding the yolk; outside that is the air like the membrane of the egg; and round all is the fire which closes it in as the shell does."

Besides the conception of the earth in the form of an egg there was the view of the earth in the form of a wheel located in the middle of the universe and surrounded by the ocean. Details of this view are lacking but the air of magic remains. For example, this earth is bounded on the north by the Caucasus, mountains of gold which no one can reach because of dragons, griffins, and men of monstrous shape. How the author of this scheme knew that the Caucasus were made of gold, when no man could reach them, is hard to see. Yet there were others who went on to describe parts of the world where nobody had ever been or could be. Such was Honorius, who tells about the terrestrial Paradise in the Far East in a locality inaccessible to man; of the four rivers which have their sources in Paradise; of the torrid zone uninhabited by man; of fantastic islands, called Antillia, not discovered by anybody.

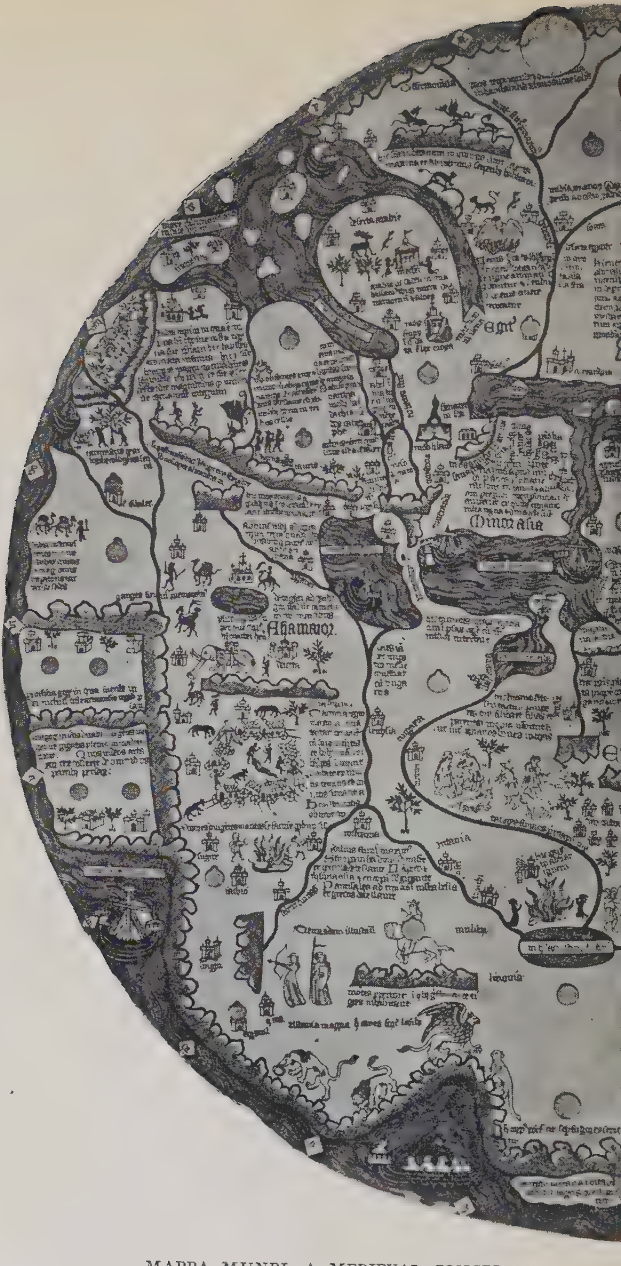


THE WORLD ACCORDING TO COSMAS

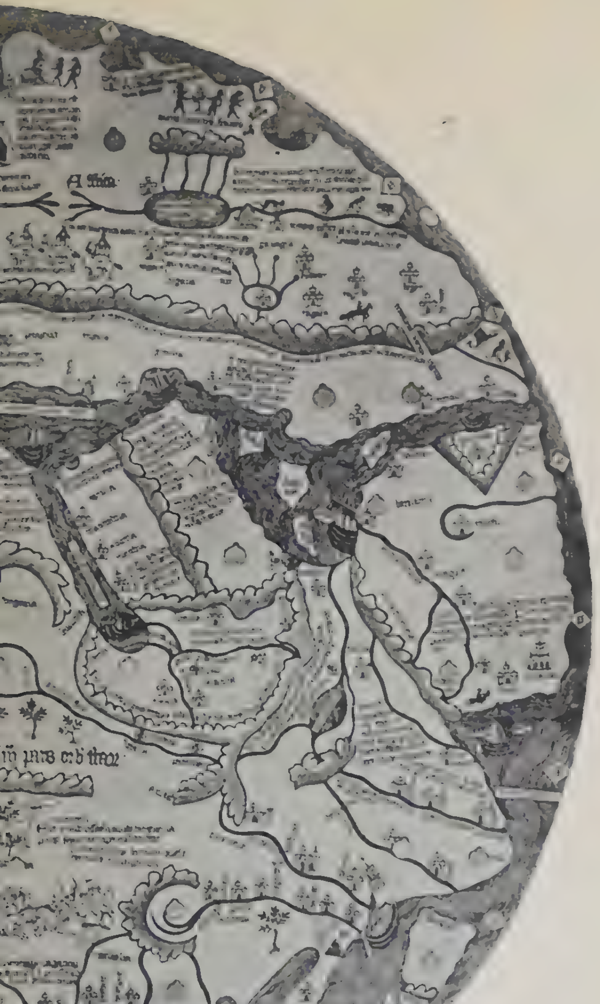
One of the best known of these fanciful worlds was that of Cosmas. This was based on the supposed plan of the Jewish Tabernacle. Cosmas' diagram puts man within four walls; these and the round top form the sky and the dome of heaven. Man cannot get out of this structure, but Cosmas evidently could, for he described another earth beyond the ocean. Here man dwelt before the flood and from that antediluvian land came Noah in his Ark. There are other details which Cosmas is good enough to give us, but which are hard to picture. The tabernacle was supposed to be divided into two stories, man living in the first, which extends from the earth proper to the firmament. On this firmament rest the waters above the earth. The second story is the heaven of the stars, where dwell the angels, since they cannot go any further, for above this is heaven proper, the paradise of God.

Cosmas' scheme is certainly a curiosity, yet it satisfied many. Being built on the Bible, at least in its language, it was opposed to the views of the Greeks, for the Greeks were pagans. So what those heretics and unbelievers had gained in knowledge was now lost. This loss can be measured by some of the medieval arguments, such as these: The earth is not round but flat, otherwise our senses deceive us. The earth does not revolve, but it is the sun that moves, as anybody can see. At night *sol occidens,* or the setting sun, hides behind a great mountain, and in the morning *sol oriens,* or the rising sun, comes out from beyond this mountain.

Thus Scripture and the evidence of the senses are preserved and the world is made safe for orthodoxy. Yet Cosmas, living in the sixth century, should not be held entirely responsible for this slump in science. There were others before him who clung literally to the Scriptures and were fond of attacking the heathen. St. Basil in the fourth century calls Greek science futile and foolish and tells his hearers about "the mysterious marvels of this great city of the universe." Likewise



MAPPA MUNDI, A MEDIEVAL CONCEPTION OF TH



RAPHICAL ARRANGEMENT OF THE WORLD

St. Augustine about the same time declares that science is only useful to help Christians understand the Scriptures, and speaks against "the vain and furious desire of investigation palliated under the name of knowledge and science." To scrutinize the secrets of nature, he adds, is beyond man; it does nobody any good to know them.

Ignorance was evidently bliss to the early Church Fathers and for this there was a reason. St. Augustine was opposed to Greek views of nature because his views were the direct opposite. The god of Plato, for example, was a god who was an architect or organizer of materials already in existence. The God of St. Augustine is a miraculous creator of matter itself, for he makes it out of nothing. St. Augustine thus briefly sums it up in the form of question and answer: "How didst Thou make heaven and earth. . . . It was not as a human worker fashioning body from body, nor didst Thou hold anything in Thy hand wherewith to make heaven and earth. . . . Thou didst speak and they were made."

A thousand years later, in the golden age of the Church, the thirteenth century, St. Thomas Aquinas repeats the same doctrine in a more elaborate way. In his great *Summary of Theology*, the official guide book of medieval belief, he speaks as follows: "God's fundamental attribute is that of a Creator; in other words, He can make something out of nothing, and He alone can create. There is no creation in the works of nature and art but these works always presuppose some preëxisting matter."

§ 21. *Dante, the Poet of the Supernatural*

Nothing could be clearer than the contrast between the pagan and the scholastic ways of looking at the world. Because of scholasticism, or the system of the medieval scholars of the Church, the ancient science was forgotten and another age of mythology brought in. Hence arose the "Christian Epic," the story of the soul's adventures in this life and in the life to come. Old Homer had once pictured the wanderings of Ulysses, had told how he escaped Sirens and Cyclops, how by the aid of the gods he was brought safely back to his home. This is the pagan epic. The Christian epic is like it. Dante, the great poet of the thirteenth century, portrays the dangers and difficulties which man in his pilgrim's progress must undergo in order to escape destruction and obtain salvation.

There is a curious fresco in Florence which puts this in a simple way. In it we see two sets of human beings and what befalls them. The good have to struggle upward on the hill of life, for it is an arduous ascent to where Adam and Eve dwell in the earthly paradise. The evil do not exert themselves; they take the broad and easy way that leads to destruction. In this picture a touch of the supernatural is brought in. The good are helped upwards by angels while the evil are pushed downwards by devils. At the top of the picture is another curious touch. In the original the arching bands

DANTE

in the sky have all the colors of the rainbow. They stand for the paths of the planets with their proper colors, such as red for Mars and blue for Venus.

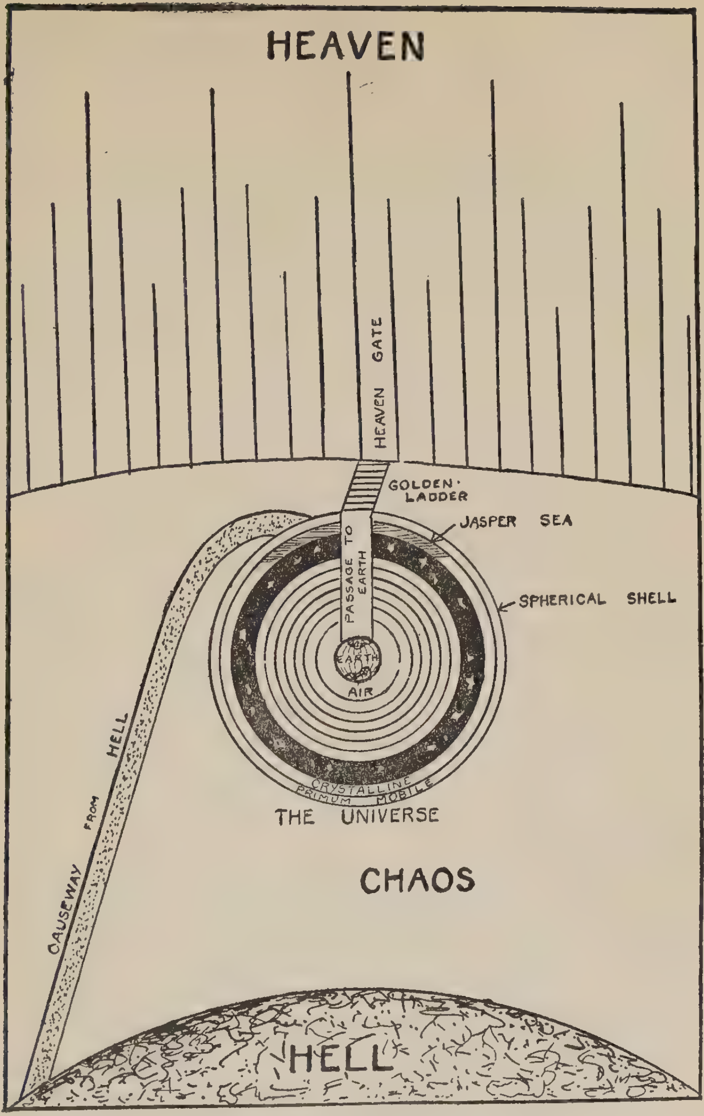
This picture is only part of a larger one. The universe of Dante is like an immense target whose bullseye is the earth and whose encircling bands are the paths of the seven spheres. In addition, within these are the zones of the elements water, air, and fire, and outside of all the crystal firmament. This we recognize as largely the scheme of Ptolemy. Dante took it over and made it supernatural. The paths of the spheres became the seven heavens, and the crystal firmament the abode of the blessed. Dante likewise added to this scheme. His epic describes paradise. It also describes inferno or hell. This is the dark side of the picture and could have been derived from two sources. The Old Testament writers had it in their Sheol, the place of departed spirits. The Greeks and Romans also had it in their infernal regions, the underground abodes of the wicked. Beyond the rivers Acheron and Styx, Tantalus is punished with his unquenched thirst, Ixion whirls on his wheel, and Sisyphus ever rolls his great rock up a hill only to have it roll back again. Yet Dante is no copyist but an original artist. So he puts in countless picturesque details to his poetic plan of the universe. To reach heaven the soul sails through the Jasper Sea and ascends to the Golden Gate by the Golden Stairs. To reach hell there is a broad and easy causeway to descend.

The infernal regions are now all mapped out and repeat within the earth the scheme that lay in the heavens. Here there are circles where the wicked meet with their proper punishments. In these descending circles are the debauched tossed by the winds, prevaricating judges in boiling wax, forgers covered with leprosy. In the last circle, or the region of Judas, Lucifer is enchained. This is the center of the earth.

Such is the Christian epic of the Middle Ages. How it was elaborated, how it grew to be dominant, is an extraordinary story. Its materials were the sacred Scriptures and profane mythology, scholastic speculation, and travelers' tales. It was built up stone by stone through the centuries until it loomed over men's minds as do the towers of a cathedral over a town.

The system of Dante was a great work of art. As a poetical structure it lasted until the time of Milton and his masterpiece, *Paradise Lost.* But it has no claims whatever to science and contained other errors of the past than those we have yet mentioned. We recall the crystalline sphere, the blue vault of the sky studded with stars as with golden nails. This was the eighth sphere of Dante. Beyond it there had to be a ninth, an outermost ring from which all that was within gained its movement. This, in the language of the Middle Ages, is called the first movable matter. The notion of this "outermost rotation" was gained from Aristotle, who also assumed that there was a Prime Mover, the Creator himself, who first set the world in motion. His relation, then, to the world is much like that of the figure of astronomy in Raphael's famous wall painting in the Vatican. But according to the Church matter itself cannot be the abode of spirit, so a tenth and final sphere is added. This is the empyrean, the heaven of flame or light where dwell the blessed spirits and the Supreme Spirit.

RAPHAEL'S FIGURE OF ASTRONOMY



THE UNIVERSE ACCORDING TO DANTE

This is a strange and fragile scheme bound to fall at the first touch of rude fact. It needed no magic wand to destroy it, only the simple telescope of Galileo. What happened was briefly this. With the telescope it was found that the stars are not fixed like gold nails in the sky, but travel freely in space, and that the planets do not derive their motion from a great revolving mass of matter (the outermost rotation) but have a proper motion of their own. Moreover the earth revolved of itself and was not the fixed center of the universe. Lastly, with his improved telescope, Galileo discovered that there was more than one world, in fact, a plurality of worlds. In place of empty space he surmised that there were countless celestial bodies never conceived of before. "Vanish, ye dark vaults of heaven," he exclaimed.

These things of course were heresies. They ran counter to the teachings of the Church. If stars travel freely in space, there is no need of the theory of solid celestial spheres. If the planets, including the earth, have perpetual motion of their own, there is no need of a first mover. If there are many worlds, then this world is not the center of the universe, the only abode of intelligent beings, the sole theater where the drama of salvation is acted.

Thus arose the great conflict between theology and reason, between the Age of Magic and the Age of Discovery. It was not so much a struggle between youth and crabbed age as between a few adventurous minds and a great and powerful organization. So Copernicus' chief work on the revolution of the celestial bodies was censored almost out of existence, Galileo was forced to recant his views on the motion of the heavenly bodies, and the overbold monk Bruno was burned at the stake for making such statements as these: "By this knowledge we are loosened from the chains of a most narrow dungeon and are at liberty to rove in a most august empire; we are removed from presumptuous boundaries and poverty to the innumerable riches of an infinite space, of so worthy a field and of such beautiful worlds."

BOOK III

The Age of Discovery

§ 22. *The Renaissance, the Rebirth of Knowledge*

To emerge from the Middle Ages is like awaking from a strange dream where everything is topsy-turvy. To the modern scientist the Age of Magic seems a swamp of superstition. There is no firm bottom of fact, and one's feet sink in a quicksand. Yet this is not wholly so. There are a few spots where one can find a footing. Such are the bits of astronomy in astrology, of chemistry in alchemy, of natural history in travelers' tales.

Yet even with the Renaissance, or revival of learning, the heritage of the past hung on. The newly discovered art of printing helped to spread true knowledge. It also helped false knowledge. Along with works by the cautious astronomer Copernicus there appeared works by the bombastic Paracelsus—astrologer, alchemist, and pseudo-scientist. With the printing press flooding Europe with books, the Church had a task on its hands. It could not control everything, but it tried to censor what seemed most dangerous. For instance, it deemed astrology a black art and declared the new astronomy a damnable heresy. Why these bits of knowledge were counted so dangerous is fairly clear. The medieval view of the universe was what might be called a comforting view. It put the earth at the center of all and man as the end of creation. This flattered man in his present life. Next the Church put heaven above and claimed that it alone held the keys of heaven. This brought assurance to man as to the future. But along came these skeptical astronomers and turned the world upside down. They asserted that the earth is but a speck in the universe and man an insect on this speck. They also asserted that heaven and earth are not two distinct realms but that both are part of one stupendous whole.

The Church was quite logical in its theory, but the theory was wrong, said the scientists. They did not make this statement openly, for they had to be careful. The burning of Bruno at the stake was a warning. So we find Copernicus acting in a most cautious manner and Galileo recanting his belief that the earth moves.

Looking back, the medieval scheme appears to many like the discarded properties in a play, and the play itself a kind of puppet show in which the Church pulled the strings. This is wrong. The men of that age were not marionettes, heaven was not filled with tinsel angels, nor hell made up of harmless red fire and stage thunder. It was a real drama thoroughly believed in at the time. It was like the opening scene of the witches in "Macbeth" which brought shudders to an audience to whom witchcraft was a dreadful reality.

Just as the English dramatist had other playwrights on whom he drew for his plots, so with the medieval theologians. The chief source was the system of Aristotle —"master of those who know," as Dante described him. This great authority reasoned that the earth must be immovable at the center of the universe, because of the heavy stuff of which it is made. While Aristarchus, as we recall, had put forward the sun-centered view of the universe, Aristotle, and after him Ptolemy, had relied on the evidence of the senses and held that the earth was the center around which revolved the star-spangled firmament. This was the general scheme to which further details were attached by the ancients. Their arguments, so curious to us, were convincing to them. Heaven, they reasoned, is the abode of the eternal gods, therefore the heavenly bodies must have eternal motion. Again, only circular motion can be eternal, therefore the stars move in circles. Heaven, therefore, has eternal, ceaseless, circular motion.

So much for the celestial regions. It is quite different down here, in what is called the sublunary sphere, or the region beneath the moon. If man sees change and decay in all around him that is because the motion of earthly bodies is not eternal and unchanging. Here every object stops at some point—the rolling stone in the valley, man in the valley of death. This point is what is known as the body's "natural place."

So far there are two main principles—eternal circular motion in the upper realm, temporary irregular motions and stoppages in the lower. Another step is now taken. There is a difference in quality between objects. Some being gross and heavy, like earth and water, their natural place is down below. Others being light and ethereal, like fire and air, their natural place is up above. And as fire ascending seeks the sun, so does the soul aspire to heaven. Hence the universe splits into two parts, the terrestial and the celestial. Ordinary language still preserves this contrast between the earthly, material, sensuous, and evil, and the heavenly, spiritual, supersensuous, and good. Below is this vale of tears; above the happy land.

Circular motion, "natural place," or the place where bodies "properly" belong, heaven and earth—these were the three main features of the medieval scheme as backed up by the authority of Aristotle. Practically everybody believed in this scheme because everything taught it. The eye was appealed to by pictures; the imagination by poems; hope and fear by the lessons of the Church. It took at least the thousand years of the Middle Ages for this world scheme to be built up. It was not to be destroyed at one blow, or by one man. It took generations of men of genius to discover the weak points and these men were by no means opposed to the scheme as a whole. Just as some great building like the Coliseum was gradually torn down bit by bit at the hands of the Romans themselves, so it was here. The doctrine of circular motion was destroyed by the astronomer; that of two distinct realms, heaven and earth, by the philosopher; that of "natural" place by the physicist; and all by men who protested that they were believers in the established faith.

So, briefly, we have Copernicus with the new astronomy, Galileo with the new physics, and Bruno with the new philosophy, all working together in undermining the old structure. With these three men there were others, sometimes pulling with them and sometimes against them. Such was Tycho Brahe who made the sun the center of planetary motion, but excepted the earth, which still remained the center of this universe. Such was Kepler who put the ellipse, or oval, in place of the circle as the true path of the planets, but still believed that the planets determined the fate of himself and his children. Such was finally Da Vinci who proved that the earth does move, but was not allowed by the Church to teach that the earth revolved about the sun. Of these men Copernicus was first and foremost, for it was he who gave his name to the new world scheme, the Copernican system.

§ 23. *Copernicus: the New Astronomy*

Copernicus was no radical. He did not wish to erase the past and make a clean sweep of all that went before. If the Church could appeal to ancient authorities so could he. As he pointed out, there were other Greek thinkers besides Aristotle who held differing views, views based on observation and not chiefly on speculation. Such were Aristarchus of Samos who put the sun at the center of the universe and Hicetas of Syracuse who believed that the earth moved. This appeal to the fathers of science was followed by an appeal to the Holy Fathers. Thus Copernicus' book *On the Revolution of the Heavenly Bodies* is dedicated to Pope Paul III. In this appeal Copernicus declared that he hesitated for a long time as to whether he should publish that which he had written to demonstrate the motion of the earth or whether it would not be better to follow the example of the Pythagoreans, or number philosophers, who used to hand down the secrets of philosophy to their relatives and friends only by word of mouth. His own friends, he added, dissuaded him from such a course. Hence after the book had lain concealed in his possession over thirty years he decided to publish it.

Thus the cautious Copernicus, writing from East Prussia in 1543, dedicates his studies to the Pope rather than to anyone else

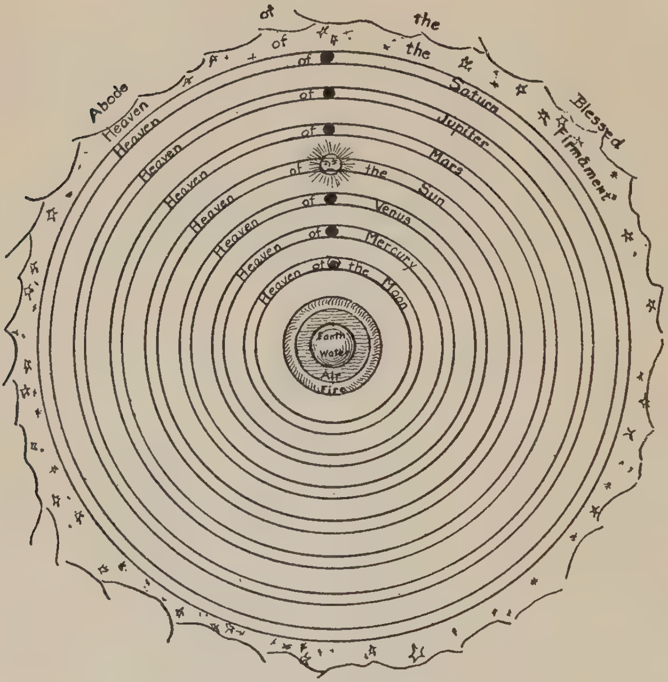
> because you, even in this remote corner of the earth where I live, are held to be the greatest in dignity of station and in love for all sciences and for mathematics, so that you, through your position and judgment can easily suppress the bites of slanderers.

Copernicus was cautious, conservative, and a bit of a flatterer. Besides this he was eloquent. He wished to make out that the earth has but a subordinate position among the other planets. So he puts it in this way:

> In the middle of all stands the sun, and who could wish to place the lamp of this most beautiful temple in another or better place? Thus, in fact, the sun, seated upon the royal throne, controls the family of the stars which circle around him.

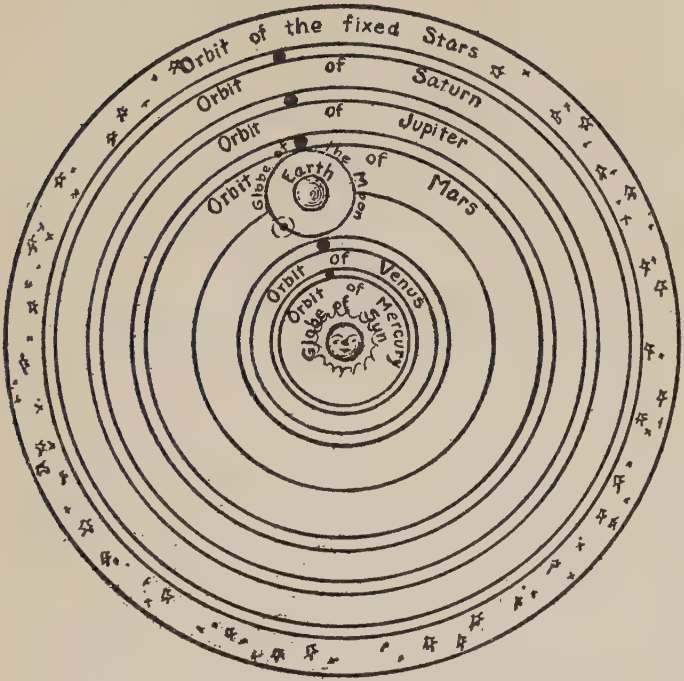
There was perhaps a delicate compliment in all this, for Rome was the center of Christendom, the Pope sat upon a throne and controlled the family of the faithful. At all events Copernicus' book passed the censor for the time being. There were two special reasons for this. One was that he wrote as if his system was only a possibility and the other that he held to some of the old views. He explained that long before this he had begun to think of a motion of the earth, and although the idea seemed absurd, still as others before him had been permitted to assume certain circles in order to explain the motions of the stars, he believed it would be readily permitted him to try whether on the assumption of some motion of the earth better explanations of the revolutions of the heavenly spheres might not be found.

This timid approach was disarming. So was the fact that Copernicus did not reject all of the old system. The Ptolemaic system had four score epicycles, or little circles revolving upon larger. Copernicus reduced these to almost half and yet could explain "the whole construction of the world and the whole dance of the planets." In other words, he put fewer links in the epicyclic chain. The planets still moved in circular motions or in paths made up of such motions. But the old chain was so complicated that astronomical predic-



THE UNIVERSE ACCORDING TO PTOLEMY

tion was made very hard. Therefore, Copernicus suggested, the Church could derive some advantage from his labors. Under Leo X, indeed, the correction of the calendar was not possible, since the length of the year



THE UNIVERSE ACCORDING TO COPERNICUS

and the motions of the sun and moon were not exactly determined. But Copernicus' suggestions finally bore fruit.

The astronomer had to give all these reasons because it was a sin to doubt an old system, based on tradition and authority. The scheme of Ptolemy had lasted almost unchanged for thirteen hundred years. Hence Copernicus declared to the Pope: "Your Holiness will be curious to hear how it occurred to me to venture contrary to the accepted views of mathematicians, and well-nigh contrary to common sense, to form a conception of any earthly motion whatever." The reason was that mathematicians, up to that time, had not been able to attain their desired end whether they used concentric circles or eccentric circles and epicycles. From these they have not been able to discover or calculate the main point, which is the shape of the world and the fixed symmetry of its parts. Their way has been as if some one were to collect hands, feet, a head, and other members from various places, all very fine in themselves, but not proportionate to one body, so that a monster rather than a man would be formed from them.

> Therefore [concludes the new astronomer] I began to grow disgusted that no more consistent scheme of the movements of the mechanism of the universe, set up for our benefit by the best and law-abiding Architect of all things, was agreed upon by all philosophers who otherwise investigate so carefully the most minute details of this world. Wherefore I undertook the task of rereading the books of all the philosophers I could get access to, to see whether any one ever was of the opinion that the motions of the celestial bodies were other than those postulated by the men who taught mathematics in the schools.

Such is the dignified dedication of Copernicus' great book which his various friends from bishops to cardinals urged him to publish. For some reason the copy of the printed work did not reach him until he was on his deathbed and the particularly sad thing about it was that he had already lost consciousness. In spite of the cautious way in which it was put forward Copernicus' theory was literally revolutionary. It offered a choice between two theories. These may be put as alternatives. Either the sun, moon, planets and stars revolve about the earth, or the earth revolves about its axis and the heavens only seem to revolve. Which theory should one choose? As Copernicus himself declares, it is more probable that the earth turns about its axis than that the planets at their various distances, the comets sweeping through space, and the endless multitude of the fixed stars describe the same regular movement about the earth.

This argument is based upon the principle of relative motion. This is not so difficult to grasp in the case of Copernicus. The old view made the model of the heavens to be a mighty framework which moved about the observer. It was really a great optical illusion, just as if a child in a swing might think that it was not he but the ground which was swinging. Besides the principle of relativity Copernicus used the principle of simplicity. He asked if it would not be simpler to have the small mass move in its petty path rather than to have the whole great mass move around the smaller. Now this principle of the simplicity of nature does not always hold. The modern view of evolution, for example, holds that nature is by no means as simple as people are apt to think, but immensely complicated, lavish, and even extravagant in the realm of life. This view holds for a system of animate nature. However, the world as a machine, from the astronomical point of view, could be explained in simpler terms than the medieval model, "the sphere with centric and eccentric scribbled o'er, cycle in epicycle, orb in orb"—as the poet put it.

Copernicus chose the simpler way by reviving the true Greek conception of the sun-centered universe. If the observer imagine himself to be placed in the sun all objects fall into their proper place, just as do the parts of some immense engine when looked at from the proper angle.

Naturally all did not accept this view, even among the astronomers. Thus Tycho Brahe, the Dane, had a chance to choose the new scheme. Instead, as we shall see, he made a compromise. The sun, he argued, might be the center of some of the planets, but not of all; the earth is no wanderer in space but the stable center around which other celestial bodies turn. His is a curious contrivance where, in order to save appearances, the earth is still in the most prominent position, while the sun is just off to one side. But even this compromise would not do for many. The out-and-out opponents of Copernicus stuck at the notion of a moving earth. They argued that, if the earth rotated in twenty-four hours, loose bodies would be thrown off, falling bodies would not fall, and the clouds would be left behind in the west.

These objections seem absurd now, but they did not seem so in that age. The discovery of the laws of falling bodies needed a Galileo and the law of gravity a Newton.

Copernicus was complimented by being called the new Ptolemy. But just as the ancient Greek needed many investigators to make his scheme work so did the astronomer in the new age. His scheme was not yet proved, and it took time to prove it. There was need for several things, and in the next two centuries these needs were met by a kind of international league of men of genius. Here Copernicus, the Pole, was the theorizer who furnished the grand outline. Next came Tycho Brahe, the Dane, who with his improved astronomical instruments furnished more accurate observations over long periods. After him arose Kepler, the German calculator, with his improved mathematical methods, who supplied the calculations for the reduction and interpretation of these observations. Kepler was followed by Galileo, the Italian expositor who supplied clear thinking as to the fundamental facts and laws of motion. Finally appeared Newton, the English generalizer who summed up all in his grand principles regarding the laws of gravity.

This great advancement of science, perhaps the greatest in the history of the race, took two centuries. Meanwhile we turn to one man who was not an observer or calculator, not an exact scientist, but a true philosopher in the sense of taking the results of the labor of others and working them up into a vast imaginative world picture. This was the Dominican monk, Giordano Bruno, who boldly accepted the system of Copernicus and as boldly faced death in its defense.

§ 24. *Giordano Bruno, the Philosopher*

Copernicus was cautious, Bruno was not. One was a cool thinker from the north, the other a southerner whose fiery temperament has been explained as due to his birth near Mount Vesuvius. That is fancy. The fact was put better by Bruno himself. He knew his own nature—ardent, impulsive, unconfined. So he admitted that in entering the Dominican order of monks he had made his initial mistake. As he expressed it, he started to button the first button wrong, so all the rest were wrong.

Copernicus was Bruno's first real teacher in science. But the pupil went further than the master. The older man had put the sun at the center of the universe, but had kept the universe within limits. These limits were marked by the eighth sphere, the crystalline vault of heaven. The younger man now asks, if an eighth sphere is assumed, why not a ninth, a tenth, and so on indefinitely? Copernicus himself did not see how far his discoveries could carry him. When he changed his standpoint from earth to sun the known universe really grew larger, just as when we travel along a road the landscape opens up and new horizons appear.

This kind of reasoning gave Bruno his primary principle—the infinity of the universe. It was helped out, in the meanwhile, by what the Danish astronomer Tycho Brahe had discovered about the paths of comets. These strange visitors to our skies he found come to us from distances unthought of before. Where then can we stop if the comets go right through the so-called crystal sphere?

The infinity of the universe is Bruno's first principle. His second follows naturally. This was the plurality of worlds. Just as we never are satisfied with a fixed point of view but must move on, so, says Bruno, we must have new worlds for old. There is a restless spirit which drives us to this. Bruno, the wandering monk, calls this self-knowledge the new knowledge. It was by this, as he said, that "we are loosened from the chains of a most narrow dungeon and set at liberty to rove in a most august empire."

It is clear that while some of Bruno's arguments are based on facts, others are based on his own feelings, and still others on a combination of fact and feeling. Such are the points he makes about his third principle—the uniformity of nature. This means that all things everywhere are under the same laws. If this be so, it makes total nature a kind of "United States of the Universe." However, Bruno does not express this in a political but in a poetical way. He bursts forth as follows:

> It is not reasonable to believe that any part of the world is without a soul, life, sensation, and organic structure. From this infinite All, full of beauty and splendor, from the vast worlds which circle above us, to the sparkling dust of stars beyond, the conclusion is drawn that they are an infinity of creatures, a vast multitude, which each in its degree mirrors forth the splendor, wisdom, and excellence of the divine beauty.

Bruno has now gone off into what is called pantheism —the doctrine that everything is divine, and that the universe is alive to its smallest nook and corner. Some of the Greeks held this view. They declared that divine intelligence was spread through the universe like water through a sponge. Bruno explained that this universal intelligence was the infinite ether which bears all things in its bosom and sends them forth from itself. In this infinite ether the planets move by their own inner soul force. This means that they were not started by the push of a prime mover, or kept rolling on by attendant angels. Lastly this infinite universe forms a system of countless worlds. Each of these moves about its central sun, leads its own proper life, grows from chaos, or ugly disorder, to cosmos, or beautiful order, and again yields to "the destiny of dissolution."

This system has been called pantheism, and pantheism is considered by many a dangerous doctrine. It might better be called in modern phrase a system of animate nature and let go at that. But for his own day and generation Bruno went too fast. He ran ahead of the schedule of discovery and met with disaster. It took two centuries more to gather proofs for his principles and the few proofs he himself had at hand did not convince the body to which he belonged. That body was the Church, and it naturally felt towards him as a capitalistic business concern would feel towards a communist in its employ.

To the Church Bruno's system was as full of heretical errors as a floating mine is full of contact points. Touch any one of these and you will be blown into eternity. These danger points were as follows: If the universe is infinite, and God by definition is infinite, then the universe is divine. But the Church teaches that the universe is half good and half evil—there is heaven above and the earth, with the lower regions of the wicked, below. Next, if there is a plurality of worlds, then there would have to be a plurality of revelations. But the Bible came only once and to one world—this one. Finally, there is the uniformity of nature. This is against revelation and against Aristotle—master not only of those who thought but of those who had their thinking done for them. Bruno might argue that there is one law throughout the universe because one God rules all. But that does not follow, said the scholars, for we know from both Aristotle and Ptolemy that the heavenly bodies move in perfect circles, while everything beneath the moon moves in erratic ways, up and down, this way and that, so that there is no telling what things will do in this world of woe. There is perversity in inanimate objects, as the saying is.

Bruno had little show against such arguments. Practically everybody believed in them. For one thing, the regular laws of motion—from comets to cannon balls—had not yet been discovered. Tycho Brahe had already surmised that comets came from beyond the realms of known space, but Galileo had not yet shown that these heavenly apparitions obeyed the same laws as the iron ball shot from the cannon's mouth. Bruno was ahead of his age and as usual suffered for it. His attempt to free men's minds was about as futile as John Brown's raid on Harpers Ferry. They caught him and they killed him.

He had left Italy when first suspected of heresy or wrong doctrine. He had wandered into Switzerland, France, England and Germany and always with this idea in his head—to loose his fellow creatures "from the chains of a most narrow dungeon." But his fellow creatures were not yet ready to be released. Thus the young Venetian nobleman who engaged him as a teacher accused him of teaching the black art, the authorities of Venice surrendered him to the Inquisition, the Inquisition handed him over to the Governor of Rome with a request that he be punished "without shedding of blood." Bruno knew that this meant burning at the stake. He never quailed. He turned and said: "Ye who pass judgment over me feel, maybe, greater fear than I upon whom it is passed."

§ 25. *Tycho Brahe, the Observer*

Bruno, as we have seen, ran ahead of the schedule of his time. The new astronomy of Copernicus did not justify all that he drew from it. In a word, Bruno was imaginative and in too much of a hurry. What the new science needed was better astronomical instruments and more accurate observation over long periods of time. These were supplied by Tycho Brahe, the great observer of Denmark. The contrast between him and the Italian is marked. Bruno loved the general and grandiose; Tycho sought the particular and precise. Bruno talked about immeasurable and countless worlds; Tycho made measurements and counted the stars. Bruno worked anywhere and spun his fancies across Europe; Tycho worked in an observatory on an island in the Baltic and became what his successor Kepler called "the prince of the mathematicians of a century."

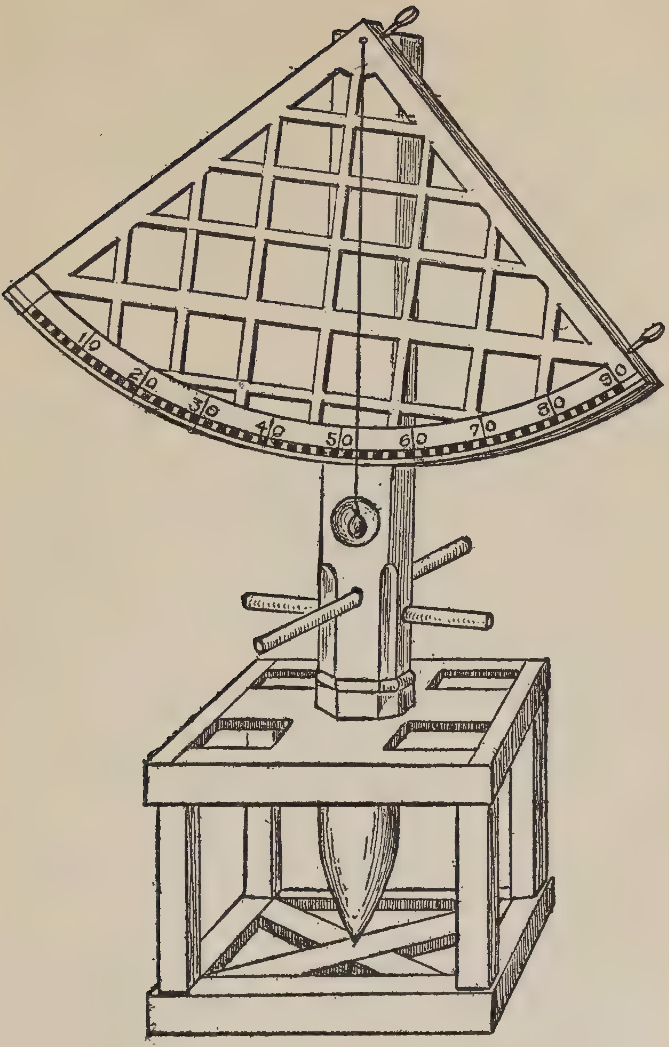
Tycho was the first great observer in astronomy. He became interested in the subject as a boy. In 1560, at the age of thirteen, he watched the eclipse of the sun of August 21. When it appeared as predicted, he made up his mind to study a science which could thus foretell the marvelous. But he could not yet brush away the old cobweb of popular belief. Three years later he observed a conjunction of Jupiter and Saturn. He thought that this was the cause of the great plague of that time. In spite of this misinterpretation his scientific interest was strong. He found that the old time tables were wrong, therefore he made up his mind to improve the astronomical tables and constructed a crude contrivance to help him out. This was simply a jointed ruler with sights for fixing the position of the planets.

Science and superstition were still mingled in Tycho's mind. In 1572 there appeared a brilliant new star. This was described correctly by Tycho in regard to its place in the heavens and its changes in color and light. But with this description came this strange interpretation:

> The star was at first like Venus and Jupiter, and its effects will therefore first be pleasant; but as it then became like Mars, there will next come a period of wars, seditions, captivity, and death of princes and destruction of cities, together with dryness, and fiery meteors in the air, pestilence, and venomous snakes. Lastly the star became like Saturn and there will, therefore, finally come a time of want, death, imprisonment, and all kinds of sad things.

This seems fantastic to us, but it was merely in the fashion of that day. The next important study made by Tycho concerned a comet of 1577. Here the Danish astronomer let fancies alone, although people at that time said that comets were formed by the ascending from the earth of human sins and wickedness, formed into a kind of gas and set on fire by the anger of God. This poisonous stuff was believed to fall down again on people's heads and cause all kinds of mischief, such as bad weather, pestilence, and sudden death.

What Tycho drew from this stranger in the skies was, among other things, this, that it could not possibly be due to exhalations or gases from the earth, because it

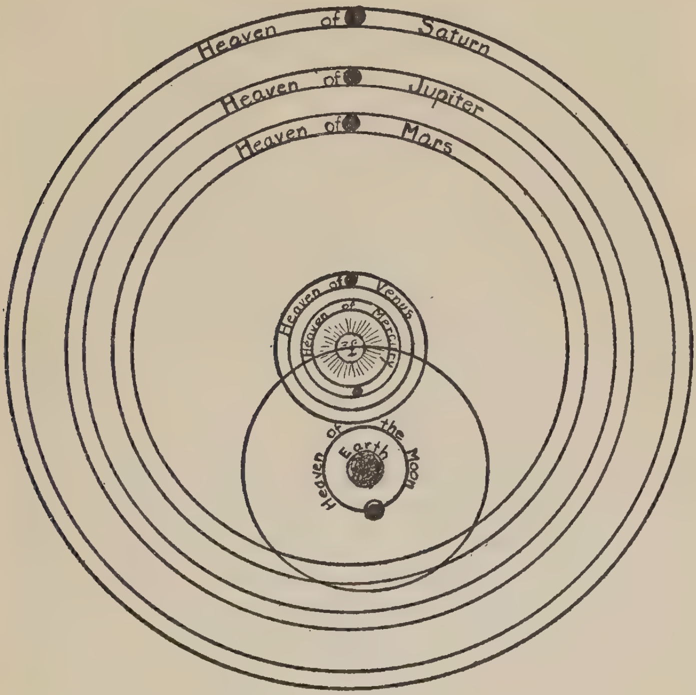


TYCHO BRAHE'S QUADRANT

was at least three times as far off as the moon. This disposed of the popular superstition. The second conclusion was that the comet was revolving about the sun at a greater distance than Venus and that it was not stopped or slowed up by the crystalline spheres. Tycho thought that the comet's path might be oval; at any rate it cut right through the so-called solid spheres. This was a body blow to the system of the Aristotelians, as the Middle Ages understood the heavens were made up of transparent solids.

These last observations and studies were carried out at Tycho's great astronomical observatory, built through the generosity of the King of Denmark on an island near Elsinore, the reputed castle of Hamlet, Prince of Jutland. This establishment was called Uranienborg, or the castle of the heavens. Besides four observatories it contained dwelling houses for the workers, shops for making instruments, and a printing press to publish results. This famous place was visited by scientists, statesmen, and kings. Its show piece was the great mural quadrant. This was a polished brass arc, graduated or marked off into degrees, minutes, and seconds. To this arc were attached two sights. As represented in Tycho's chief book we see him pointing towards a certain star, one assistant peeping through a sight, another taking the time from a clock with two dials, and a third, at a table, recording the observation. This book also shows Tycho's chemical laboratory, rooms where his students are at work, and two balconies containing such instruments as an astrolabe or skeleton celestial globe, a sextant for measuring the angular distance between two bodies, and a quadrant for finding altitudes.

This place, the Lick Observatory of its time was a true temple of science. As Tycho designed and superintended the making of his instruments and as they had the backing of the royal treasury they were the best money could buy. But with all this equipment and with twenty years of observation Tycho could not accept the Copernican scheme. For example, he made the objection that, if the earth rotated, a stone dropped from the top of a tower would fall at a distance from the foot of the



THE UNIVERSE ACCORDING TO TYCHO BRAHE

tower. Again he declared that if the earth moved in an orbit about the sun, this yearly motion would put the sphere of the fixed stars off to such a distance that the path described by the earth must be insignificant in comparison.

Tycho saw such difficulties in the Copernican system that he made a curious compromise. He abandoned the Ptolemaic scheme where the earth was the bull's eye in the cosmic target and where the paths of the sun, planets and stars formed the rings of that target. But he could not go so far as to discard all of this system and make the sun the center of all. Instead of having, so to speak, one circus of several rings with the sun as the central attraction, he put the sun off in a side show, and surrounded it with all the planets except the earth. That left the earth still at the center and the rest of the circus revolving around it. This was somewhat trivial. However there were compensations. Tycho's theory did not last, but his exact observations did. Such were his tables of over seven hundred stars, and a copper globe with the positions of one thousand stars marked upon it. These were inherited by his pupil and successor Kepler, whom we may call the calculator in the advancement of the new astronomy.

§ 26. *Johann Kepler, the Calculator*

Tycho the Dane at his astronomical paradise in the Baltic had carried on a magnificent series of observations for over twenty years. It remained for his pupil Kepler to reduce and interpret these observations. Figures cannot lie, but they also cannot tell the truth by themselves. Tycho was so busy making observations and had made so many of these that he was nearly swamped in his riches. So Kepler, the patient German, devoted a quarter of a century to working out his master's records. To patience he added genius. He had before him a mass of figures, representing a maze of motions, yet in these he at last discovered the three famous laws of motion which bear his name. These were justly famous, for they straightened out the old tangles and put law and order among the heavenly bodies.

Kepler did not attain his position of command without trouble. He had been through the mill. Unlike Tycho, he was of humble birth and poor. So he had to work his way up by petty jobs. Appointed a lecturer in mathematics at Gratz, where students were few and fees small, he was obliged to eke out his living by catering to the tastes of the time. This he did by getting out a yearly almanac, somewhat in the style of the old *Farmers' Almanac.* This contained some facts and also much fiction, such as weather predictions and astrological tips.

As he expressed it: "Mother Astronomy would surely have to suffer hunger if the daughter Astrology did not earn their bread."

Kepler's first book was called *The Cosmographic Mystery,* and in spite of its fancies it was welcomed by both Tycho and Galileo. It showed that its author had geometric ability, but that his imagination needed weights and not wings. These were supplied by Tycho, who wrote to Kepler, "Come, not as a stranger, but as a very welcome friend, come and share in my observations with such instruments as I have with me and as a dearly beloved associate."

Kepler having made one attempt now made another. He took up a hard problem, that concerning the motion of Mars. The path of this planet, as it appears from the earth, is as crooked as the flight of a boomerang. Try as he would Kepler could not explain this in terms of circles. Some combinations might agree with the observations of Tycho, but the best he could make was wrong by eight minutes of the arc. Now Kepler knew that Tycho, with his great mural quadrant, would never make such a mistake as this. So he gave up the idea of uniform circular motion and tried dividing the circle up into eccentric triangles. His diagram here looks like a pie cut into pieces, not from the center but off to one side. This seemed to do for some time. But new errors arose, and the path of Mars could not be explained in this way. As he quaintly put it:

> While thus triumphing over Mars, and preparing for him, as for one already vanquished, tabular prisons and equated eccentric fetters, it is buzzed here and there that the victory is vain, and that the war is raging anew as violently as before.

> For the enemy, left at home a despised captive, has burst all the chains of the equations, and broken forth from the prisons of the tables.

Kepler is a true scientist. He uses the method of trial and error and is frank as to his failures. He is an explorer and explorers make mistakes. He declares that if Columbus, Magellan and the Portuguese wandered off the course, no one should blame him for doing the same. Kepler tried circles and triangles inscribed in circles to explain the path of Mars. But these would not do. Now he suddenly hits on another figure and that is the ellipse, or the curve made by cutting through a cone on the bias. This form of the oval to his great joy he finds works perfectly. Mars is conquered and more too, for this discovery is made general and becomes what are known as Kepler's first two laws. These are as follows:

> A planet describes an ellipse, the sun being in one focus, . . . and a straight line joining the planet to the sun sweeps out equal areas in equal intervals of time.

The third law is more complicated and completes the work of Kepler. When he published it in his *Harmony of the World* he exclaimed:

> What sixteen years ago, I urged as a thing to be sought, that for which I joined Tycho Brahe, for which I settled in Prague, for which I have devoted the best part of my life to astronomical contemplations—at length I have brought to light, and recognized its truth beyond my most sanguine expectations.

Kepler's predecessors had greatly confused matters with their cycles, epicycles and movable eccentrics, but

Kepler himself now stepped in and straightened out the tangle. The old way was to go in circles, the new gave that up. To those used to the old routes it was irritating to be directed into detours, to go off into ellipses and hyperbolas and other strange curves. But by making these detours around congested districts the traffic was kept moving in an orderly way.

Beside new routes there were new speed limits. Instead of circles and uniform motion the new laws said that any planet, as it nears the sun, must go slowly, but that as it goes further off it must go faster. The results showed that this scheme was correct. When Galileo turned the newly invented telescope to unexplored regions of space the laws of Kepler were found to be universal laws. This, then, marks the third great step in the advance of the new astronomy. Tycho the Dane had made observation of the heavenly bodies; Kepler the German had made calculations as to their paths and speed limits; Galileo the Italian now furnished the verification by discovering the laws of motion of bodies, from cannon balls to comets. His point of view he gave as this:

> Philosophy is written in that great book which ever lies before our eyes—I mean the universe—but we cannot understand it if we do not first learn the language and grasp the symbols, in which it is written. This book is written in the mathematical language, and the symbols are triangles, circles, and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wanders in vain through a dark labyrinth.

§ 27. *Galileo, the Expositor*

The new astronomers before Galileo had furnished the blue print for the parts of the world machine. They had traced out the curves and shown how the various portions worked, but they did not know by what force they moved. The next problem then was to discover the motive power which made all bodies, great or small, act as they do act. This problem was taken up by Galileo the Italian, who was born in Pisa, lectured at Padua and Florence, and finally fell into the clutches of the Inquisition at Rome.

Galileo's first experiments were in the field of physics and concerned the laws of bodies in motion or at rest. The old physics, like the old astronomy, suffered from the mortmain of the past—the dead hand of authority resting heavily upon it. That authority was Aristotle, who declared that the velocity of falling bodies was proportionate to their weight. This would mean that a two-pound weight would fall twice as fast as a one-pound, a three-pound weight three times as fast, and so on. There may have been some excuse for this statement if small bodies are meant. If a coin and a feather be dropped at the same time from a man's hand the coin reaches the ground first. This is because of the resistance of the air, but Aristotle's explanation would have involved also the old notion that heavy bodies tend to move rapidly to their "natural" place, the heavy earth, and that light bodies remain in the atmosphere which is "by nature" light.

Galileo swept aside this false theory and this lack of observation by a simple experiment. He took to the top of the leaning tower of Pisa two weights, a shot of one hundred pounds and another of one pound, pushed them over the edge and let them drop together. They struck the ground at the same time. The experiment was a success, but many could not believe the evidence of their senses. The old Aristotelians declared that the young Galileo had done the trick through some unknown cause, probably by the aid of magic.

Galileo's experiments made him unpopular at Pisa. He found a scientific refuge in the Republic of Venice, which was more or less free from the fetters of tradition. At Padua he carried on further experiments. These dealt with the velocity of falling bodies. According to the old idea, weight determined the speed with which bodies reached the earth. Galileo had shown that the small cannon ball did not lag behind the larger when dropped from the tower. But he did not know what their common speed was. He now rigged up a smooth inclined plane and down it rolled a bronze ball. Then by means of a water clock he found out that a body will be falling at the rate of 32 feet per second at the end of the first second, 64 at the end of the second, 96 at the end of the third, and so on. In other words a body falls 32 feet faster every second until it reaches the ground. This was exact science. It furnished a fact instead of a fancy. The fact is the law that falling bodies move with evenly increasing speed through their course. The fancy is that a body hastens toward its "natural" place, just as a man hastens more and more eagerly the nearer he gets to his fatherland.

Another set of exact results obtained by Galileo concerned projectiles. People at that time did not know exactly what was the line of flight of a ball fired from a cannon. Galileo showed that a ball begins to fall as soon as it leaves the cannon's mouth and describes a parabolic curve. This is due to the fact that the force of gravity begins to act at once. So instead of a simple motion due to the powder and a simple motion due to gravity we have a compound motion resulting in a kind of curve familiar to any one who keeps raising the sight of his rifle the farther off the target is. These new ideas had to be corrected as time went on. Some details were left out. For one thing the resistance of the air was not fully allowed for. Galileo of course declared that the air was a hindrance and not a help and that it did not rush in behind and make a body go faster. But the clear proof that a feather and a coin would reach the ground at the same time under proper conditions could not be furnished until the experiment was tried in a vacuum, such as in a vessel exhausted of its air.

However, Galileo had laid the foundations of modern mechanics in regard to small bodies. At the same time he furnished a mass of new materials in regard to great bodies, especially the celestial bodies. This was made possible by means of the discovery of that new instrument the telescope. Who discovered this is not precisely known. Some claim that Roger Bacon in the thirteenth century put certain lenses in a tube and opened up the skies to man's vision. Some recently discovered writings of the English monk have extraordinary pictures of spiral nebulae or rotating star clusters. If Bacon did discover the telescope he kept it a secret. He was probably afraid of claiming to have explored the skies beyond the crystalline vault, just as some of Galileo's friends were actually afraid of peeping through his telescope lest they should "fall into heresy," as the saying was.

By Galileo's time the telescope was being used. Its invention was claimed by two different firms of Dutch spectacle makers. One story goes that some children were playing with lenses one day and noticed that if two of them were looked through at once, the clock on the distant steeple came out so clearly that the time could be read on it. Whatever the legend, the fact is that Galileo heard of the Holland spyglass and at once set upon improving it. With his knowledge of the laws of optics he was able to construct an instrument that made objects seem thirty times nearer and a thousand times larger than when viewed with the unaided eye. Now followed an astonishing list of discoveries, for a new instrument always brings great results. Take nowadays the invention of the gas engine. From it have followed airplanes, fire pumps, tractors, submarines, motor cars of all kinds; in short, air, fire, earth, and water, all the elements, have one by one been conquered and made subservient to man by this one invention.

So with Galileo and the telescope. He directed his little spyglass, not much larger than an opera glass, to the heavens, and here are some of the things he found: spots on the sun, mountains on the moon, phases or different aspects of Venus, four moons around Jupiter, Saturn with curious appendages, and the Milky Way not the path of a comet, but made up of a multitude of stars.

The results of these discoveries were as remarkable as the discoveries themselves. The old system was smashed in all its parts. If the sun had spots, it was no longer the perfect, immaculate body demanded by its place in the heavenly realm. If the moon had mountains and craters, it was no longer the crystal orb of night with its pure smooth face. If Venus had different phases or aspects, like the moon, it was no longer a planet fit to dwell in the unchanging heavens. The same reasoning applied to Saturn with its appendages, later resolved into rings. Finally, if the Milky Way was made up of a multitude of stars, that would make possible the doctrine of the plurality of worlds.

The general result of all this was to destroy the old dualism—the belief that there are two realms—the heavens above, perfect and unchangeable, and below the earth, imperfect and changeable. In brief, the universe now becomes one, heaven is brought to earth and earth is put in the heavens. There are no longer superior and inferior, but all bodies have equal rights.

§ 28. *The Conflict between Authority and Audacity*

With such conclusions to be drawn from the new discoveries, Galileo naturally fell foul of the Church and of that immense body of the believers who held to the old views. His experiments with falling bodies at Pisa were as nothing compared with his fresh discoveries at Padua. But the worst was to come when Galileo declared that the new discoveries confirmed the system of Copernicus. In 1613, two years after he constructed his first telescope, Galileo publicly declared that Copernicus was right and Aristotle wrong. The next year the Sacred Congregation, or Church board of censors, decreed that Copernicus' doctrine of the two double movements of the earth was in contradiction to the Sacred Scripture. It was a conflict of authority with audacity, where authority won the first few innings but audacity won the game. This conflict lasted well on into the next century. Then Newton could show that a natural explanation was better than a supernatural. This meant that universal gravity was a simpler explanation than forces exerted by angels over the orbs, or a prime mover pushing the celestial sphere.

The trial of Galileo for heresy, or wrong doctrine, was not to come for several years. Meanwhile he did not hide his views, but defended the sun-centered system whenever he had a chance. Tycho, it will be recalled, was timid and made a compromise as to Copernicus.

He brought the following objections against the theory of the earth's movements. First, the earth was too heavy. As he put it: "The sluggish earth is unfit to move." Next, if the earth moved, all loose things would be carried from east to west, they would fly off like drops of water from a wheel. Lastly, he could not conceive of the earth being turned upside down and of men hanging with their heads downward for twelve hours out of the twenty-four.

These are familiar old objections based on false assumptions and reasonings. The first is that the earth is the heaviest of the four elements whose natural state is that of rest. The second objection is based on false reasoning; it makes out that what takes place in a small body—like a cart wheel—takes place in a large body like the earth, with its immense attraction for smaller bodies on or near its surface. Galileo met this objection by the simple statement that a ball dropped from a tower falls at its foot, just as an object dropped from the masthead of a moving ship drops on its deck. The third objection is a revival of the ancient and medieval prejudice against the antipodes—the supposed region of the under earth where men could not live upside down, like flies hanging from a ceiling. This objection is met by bringing in the force of gravity.

These objections seem weak and easily disposed of. But there were greater ones much harder to meet. Beside the assumptions, based on ancient authority and the Sacred Scriptures, Tycho turns to difficulties based on observation. Why is it that the constellations always preserve the same aspect, age after age? The Great Bear or Dipper; Orion and his belt; Cassiopeia and her chair

—these fancied figures have ever remained the same as shown by the old star maps. If the earth moves why have they not changed, just as the lights of a town shift as the traveler passes by? The answer is that the constellations are at a distance practically infinite for the human eye. Copernicus suggested this and Galileo accepted his suggestion. Yet it was not until the present century that it was shown that the stars do show displacement with the seasons of the year. Because the distances are almost infinite, the differences appear almost infinitesimal. Of course Galileo could not reach these accurate results with his crude telescope made out of a length of old organ pipe.

Tycho's last objection against the Copernican system was this. If the earth revolves about the sun, Mercury and Venus ought to show phases like the moon. Copernicus predicted these phases and Galileo actually discovered them. But first he had to give proof of the powers of his telescope. This he did, as he wrote Kepler, by showing to the senators of Venice vessels that were so far off that it was two hours before they were seen "without my spyglass, steering full sail into the harbor." "My spyglass," he explains, "makes a thing fifty miles off as near and clear as if it were only five." With a better perspective glass turned towards the heavens, Galileo now discovered the phases of Venus. This means that, like the moon, the planet passes gradually from the thin crescent to the full round orb.

Here was a confirmation of the Copernican system which implied that the planets, like the moon, shine by reflected sunlight. Added proof was given by some unexpected new discoveries. The greatest marvel of all, as

Galileo himself described it, was the discovery of four new planets. These, which we now know as the four secondary planets by which Jupiter is surrounded, Galileo described as "moving in the same way as Mercury and Venus and peradventure the other known planets move round the sun."

What did the other chief living astronomer think of these things? Kepler long before as a young man had defended the Copernican system in a college debate. He had tried to prove that Copernicus was right by his curious system of regular solids, the rings or hoops around which were supposed to represent the paths of the planets. When he sent a copy of his book, *The Cosmographic Mystery,* to Galileo, the latter replied that he was glad to have found so great an ally in the search for truth, since he himself had been for many years an adherent of the Copernican theory. He had collected many arguments for refuting the accepted theory, for example, that the moon is a body like the earth. But these arguments he had not ventured to bring to the light of publicity for fear of sharing the fate of Copernicus. "Our master," he says, "who although he has won immortal fame with some, yet with very many (so great is the number of fools) has become an object of ridicule and scorn."

Galileo was cautious when he had only guesses to work upon. Now that he has observations he becomes bold and in turn holds up the fools to ridicule and scorn. One man declined to look through his telescope at the satellites of Jupiter. Upon the death of this timid soul soon after Galileo sarcastically remarked: "I hope that he saw them on his way to heaven."

When Galileo had discovered the phases of Venus and Mercury as predicted by Copernicus, a friend wrote to him that he must now convince the most obstinate. Galileo, more worldly-wise, replied that not even the testimony of the stars would suffice, were they to descend on earth and speak for themselves. Thus a professor of natural philosophy at Pisa, when requested by Galileo to look at the moon and planets through his glass, refused to do so. "What shouts of laughter we should have at this glorious folly," wrote Galileo to Kepler, "to hear his laboring before the Grand Duke with logical arguments, as if with magical incantations, to charm the new planets out of the sky."

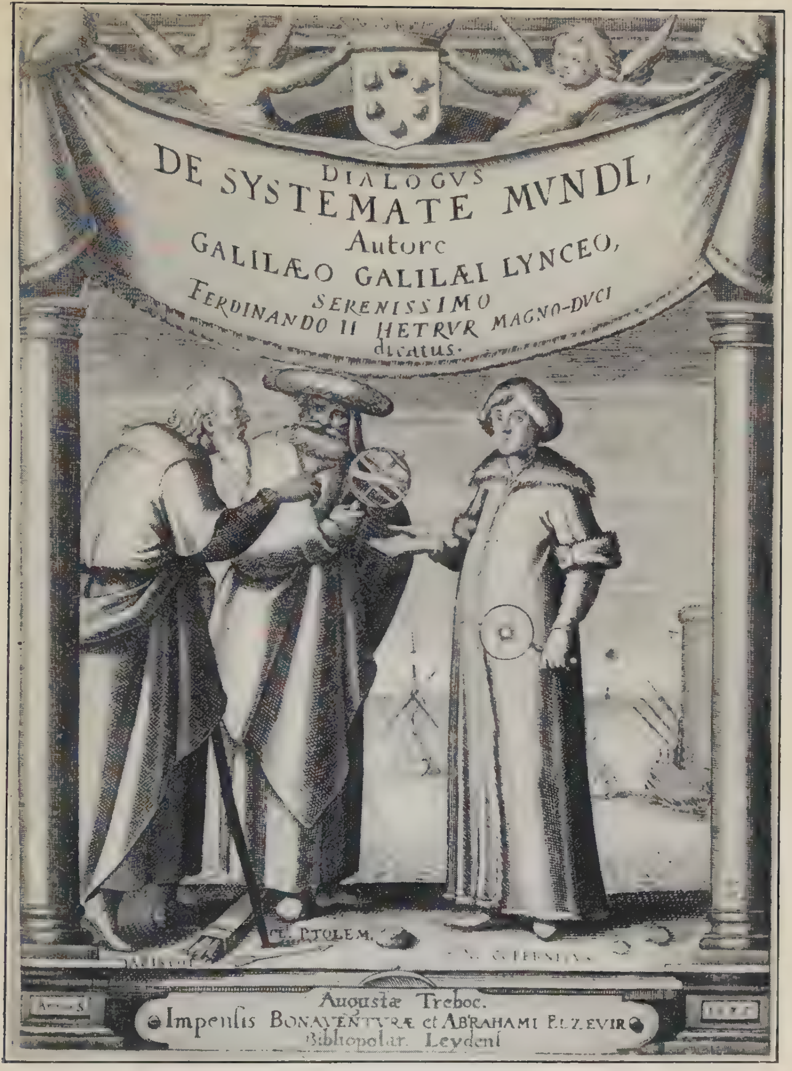
The kind of arguments used by this professor were probably like those of an astronomer of Florence. The latter reasoned in this way as to Jupiter and its moons: "The satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore will be useless, and therefore do not exist."

For the time being Galileo had the best of his opponents. These people, as he put it, believe there is no truth to seek in nature, but only in the comparison of texts. But soon Pope Paul V called Galileo to Rome to explain his views. After his audience the two apparently parted good friends. But in the meanwhile the astronomer's enemies urged both the Pope and the College of Cardinals to declare the Copernican system impious and heretical. The conservatives won. The work of Copernicus and Kepler's commentary on it were both placed on the list of prohibited books and Galileo was commanded never to teach or believe the motion of the earth. The next Pope, Urban VII, was a personal friend of Galileo's and publicly praised him on his learning, which misled Galileo into thinking that he might publish his views. This he did in his most famous work, *The Dialogue on the Two Chief Systems of the World.*

§ 29. *The Conflict of Systems*

In his great work *The Two Chief Systems of the World* Galileo chose the dialogue form so that no one could say that he did not present both sides of the question. There were two chief speakers, one who upheld the new view of Copernicus, the other the old view of Aristotle. This seems fair enough until we discover that there was a joker in the names of the interlocutors. The conservative speaker, who upholds the old view, is named Simplicio. This suggests to the reader that he is a simpleton, a man of straw put up merely to be knocked down. One story goes that Galileo's enemies at once caught at this and hinted to the Pope that it was he who was meant by this simple-minded character. And yet Galileo was not to blame for using the dialogue form in putting his views before the public. The decree which had condemned the Copernican doctrine expressly stated that it was permissible to mention that doctrine as an hypothesis or theory in scientific argument, but that it was forbidden to proclaim it as truth.

This is what is known as the double standard. Bruno had attempted to appeal to it in his trials, for he had made a distinction between speaking as a Catholic and speaking according to reason. The distinction was vain there and was vain here. Anybody could see which side Galileo favored. In the preface he speaks of the former edict against himself as imposing a reasonable



DIALOGVS
DE SYSTEMATE MVNDI,
Autore
GALILÆO GALILÆI LYNCEO,
SERENISSIMO
FERDINANDO II HETRVR MAGNO-DVCI
dicatus.

Augustæ Treboc.
Impenſis BONAVENTVRÆ et ABRAHAMI ELZEVIR
Bibliopolar. Leydenſ

TITLE PAGE OF GALILEO'S BOOK

silence upon the opinion of the mobility of the earth. But he at once adds that this edict was gotten up by people who knew nothing of astronomical observations and who tried to clip the wings of speculation. He also appeals to the patriotism of his readers and hopes that "the world will know that, if other nations have navigated more than we, we have not studied less than they."

This preface did not help matters but only rubbed the sore spots. It made Galileo's opponents appear ignorant and narrow minded. But worse was to come. When Simplicio, the Aristotelian, speaks, Salviati, the Copernican, talks to him as if he were giving information to a dull boy in school. He can hardly make him understand that there is such a thing as relative motion. Here is a sample of the *Dialogue:*

> *Simplicio:* Do you call that nothing when the sun goes from one meridian to another, rises up over this horizon and sinks behind that one, brings now day, and now night?
>
> *Salviati:* All the changes you mention are such only in respect to the earth. They may all be reduced to the simple fact that the sun is first visible in China, then in Persia, afterwards in Egypt, Greece, France, Spain, America, etc. . . . Exactly the same thing happens and in exactly the same way if, instead of disturbing so large a part of the universe—such as the immensity of the starry sphere—you let the earth revolve about itself. . . . If, however, the earth is left motionless, we must go to an incomparably greater sphere, to which we must ascribe a complete rotation in twenty-four hours.

This is the first and the chief argument against the astronomical systems in vogue before Copernicus. These systems were all based on the belief that the earth was the immovable center of the universe. But more arguments are added until Simplicio is buried beneath an avalanche of new facts. A brief of this debate would run something like this: Sun spots show that the sun is not the perfect orb of day; new stars that the heavens are not unchangeable; comets that the spheres are not solid; new satellites that there are more worlds than man ever dreamed of.

Of all these points the alleged motion of the earth was the worst in the eyes of the churchman. Grant that the earth moves and it becomes a mere side show and not the theater of divine action. This was the chief heresy, the others were incidental. So the Church must exert its discipline. Scholasticism was literally a school, and when a scholar becomes too clever for his teachers either he must be suppressed or they must take a back seat. Schoolmen would never do that because they had the power to punish. The Inquisition stood ready not with a mere birch rod but with the rack, not with the ferrule but with the torch. It was not the case where an impossible pupil could leave the school. There was no other school except the Protestant. It never occurred to Galileo to go to the latter, for he declared himself a "jealous and Catholic Christian."

What was to be done under the circumstances? It is either denial of his doctrines or death at the stake. So Galileo formally recanted his belief in the earth's motion. There is a story that as he left the chamber of the Holy Office he made an aside to a friend, whispering, "It does move just the same." This could not have happened. He had no friend in the room.

While Galileo has been called one of the martyrs of science he was neither as boldly spoken nor as brave in the face of death as was Giordano Bruno. Yet for the advancement of science he perhaps did as much as his fellow countryman. His sarcasm, his methods of arguing a matter to its absurdity, were more effective than the mere enthusiasms of the monk. Besides these Galileo left behind him his wonderful discoveries which others were to verify. And last of all there remained those documents of condemnation which gave away the whole case for the prosecution. In the formal condemnation the inquisitors put the case even more clearly than Galileo himself had done. In addition they gave wide publicity to the two rival systems. All men knew the Ptolemaic system—textbook, sermon and picture had taught it for centuries. Now Copernicus had his innings and received an immense amount of free advertising. The *Document of Condemnation* put the opposing cases, the *Document of Recantation* repeated the points, and this very repetition drew the attention of the world to the conflict between authority and audacity.

Here are some extracts:

> Whereas you, Galileo, son of the late Vincenzo Galilei of Florence, aged seventy years, were denounced in 1615 to this Holy Office, for holding as true the false doctrine taught by many, namely, that the sun is immovable in the center of the world, and that the earth moves, and also with a diurnal motion; also for having pupils whom you instructed in the same opinions; also for maintaining a correspondence on the same with some German mathematicians; also for publishing certain letters on the solar spots, in which you developed the same doctrine as truth; . . .
>
> Therefore, this holy tribunal being desirous of providing against the disorder and mischief thence proceeding and in-

creasing to the detriment of the holy faith, by the desire of His Holiness, and of the Most Eminent Lords Cardinals of this supreme and universal Inquisition, the two propositions of the stability of the sun, and the motion of the earth, were qualified by the Theological Qualifiers as follows:

The proposition that the sun is the center of the world and immovable from its place is absurd, philosophically false, and formally heretical, because it is expressly contrary to the Holy Scripture.

The proposition that the earth is not the center of the world, nor immovable, but that it moves, and also with a diurnal motion, is also absurd, philosophically false, and, theologically considered, at least erroneous in faith.

§ 30. *Newton, the Generalizer*

In the year in which Galileo died Isaac Newton was born and with him a new era. That era has been called the Age of Newton, for the great Englishman with his discovery of the law of gravity dominated it. That age may also be called new because it brought in the view of the world as a machine. Galileo had formulated the laws of small bodies falling towards the earth. Newton extended these laws to large bodies and to the very confines of the known universe. If an apple drops to the ground because attracted by gravity, the same attraction must affect the moon.

The familiar story of Newton under the apple tree may or may not be true. At least it serves to illustrate the fresh discovery, or rather the fact, that a real principle good for this sphere may be pushed into the realm of space. Here the new law is to apply to whatever may turn up—comets, meteors, satellites. Now as the telescope was made larger, the bounds of the universe were broadened, but, however widely extended, these new laws kept pace with the new findings.

So the world becomes a vast machine, more and more complicated but always working under the same laws. The diagrams in Newton's *Principles* concern such matters as the path of the moon about the earth made up of its rate of fall and its own motion. And what applies to this earth with its little satellite applies to greater planets with greater satellites and to the sun itself with comets sweeping about it in vast orbits. The blue print is enlarged, and whether it applies to a working model in miniature, or to the immense world machine, it is always in scale, always after the same pattern, always obedient to the same laws of motion.

This flexible framework of ideas is Newton's great glory. At first, as applied to our little universe, it may have appeared as a working model in a patent office which is confined in a limited place. But with the advancement of science, with the discoveries of the immense stellar spaces, such as were made by Herschel when new island universes swam into his ken, it was found that the working model was a universal model, a thing that mortal mind had dreamed of but had never before confirmed.

Newton, then, has the undying fame of being considered the great generalizer of the laws of motion. More truly than Kepler he was the legislator of the heavens, for he reduced Kepler's three laws of motion to one law, the law of gravity. The first proof of this was the quick acceptance of his views by the men of his time, the last proof the impossibility of disproving his principles even at this late day.

The chief question which Newton asked was: What makes the planets move the way they do? Their paths had been described more or less well. But there remained the problem of the efficient cause, that is, the discovery of a cause sufficient to move them. Various explanations had been made. Aristotle of old had suggested a prime mover who spun around the first matter, or outer shell of the universe. The medievals had added angels to the scheme, each of whom had charge of a rolling sphere.

Then Copernicus, the Pole, thought a body could not turn without being fixed to a crystal sphere. Next Kepler, the German, had dropped these supernatural agencies and imagined spokes of force sticking out from the sun, as if the sun were the hub of a vast wheel. Meanwhile Descartes, the Frenchman, had suggested vortices or whirlpools of matter which carried the planets along in an eddying stream. Finally, Gilbert, the Englishman, considered that a magnetic power residing in the sun was the secret principle.

All this turned out to be wrong when Newton had his way. With the simplicity of genius he took two existing forces and showed by calculation that they would account for the revolutions of the heavenly bodies. The moon was his starting point because nearest to the earth. Grant that a body has motion of its own and moves onward in a straight line; grant that it is falling toward the earth, as do all bodies near the surface, and the solution is at hand.

Of course several things must be known, such as the size of the earth, the distance of the moon, the rate of acceleration of a falling body. The last of these had been worked out by Galileo, the second by Kepler, but the first was unfortunately not exactly known when Newton began his calculations. The length of a degree, one-three hundred and sixtieth of the earth's diameter, was only roughly worked out. This was what threw Newton off the track in his first calculations.

The problem before him was this: Why does the moon always move around the earth? The natural thing is for a body, once started, to move on in a straight path. If that path is curved there must be some deflecting force.

In the case of the moon the attraction of the earth may be that force. Can this be proved? Newton asked. Yes, if the pull of the earth brings about the same rate of fall as for other foreign bodies. There are here three factors to be considered. The final circular path is the orbit of the moon, the tangent is the straight line touching any point of that circle, the pull towards the earth is the centripetal or center-seeking force. Thus with two pulls a curve is described. The shape of this curve is known. Does it agree with the law of moving bodies as stated by Galileo? That is the question that occurred to Newton. If apples and cannon balls fall to the earth at a certain rate, why not the moon at a rate proportional to its size as compared with that of the earth?

Newton went from apples and cannon balls to greater bodies and finally found that common gravity worked in the heavens as well as down here. Galileo estimated the speed of a falling body as just a trifle over 16 feet the first second. Newton tried to verify this but failed at first. His result was 13 feet, too far off to come under Galileo's calculations. The reason for this was a faulty measurement of the earth. The astronomers of that day had estimated the circumference of the earth by measuring a part of a meridian or great circle. They had not used points far enough apart to make this measurement exact. But meanwhile the French had measured a meridian from two such widely separated places as Lapland and Peru. This gave a new estimate of which Newton learned almost a score of years after his first failure. He went back to his old figure, made the necessary corrections, and when he saw the answer was coming out right he became so excited that he was obliged to let a friend finish his calculations. Eureka! The result agreed with Galileo, and the law of the universal operation of gravitation was confirmed. As the great discoverer himself summed it up in Proposition IV of his *Principles:*

> The moon gravitates towards the earth. And by the force of gravity is continually drawn off from a rectilinear motion and retained in its orbit.

Why did men at once accept Newton's *Principles,* and before the end of his life almost worship him? It was not because he discovered the force of gravity. From the Greeks to Galileo there was always some intelligent thinker who knew of that force. It was because Newton discovered and proved that our entire system was ruled by a central force coming from the sun. The control of the moon by the earth is a special case of a similar central control. So is that of the satellites of Jupiter by a force emanating from Jupiter. In a word, all the various bodies of our system obey a common mathematical law.

Even the men of Newton's day hailed him as a genius. His *Principles* were looked upon as the "Bible of Science," and he himself as a man who had confirmed the belief that order was heaven's first law. Newton's rival, the German philosopher Leibnitz, gave him the highest possible compliment. He said: "Taking mathematics from the beginning of the world to the times when Newton lived, what he has done is much the better half." Newton himself was more modest. He simply said: "If I have seen further than other men it is because I have been standing on the shoulders of giants."

These giants we are familiar with—Copernicus who brought back the view of the universe as sun-centered; Tycho who furnished a lifetime of observation; Kepler who showed the paths of the planets to be elliptical; Galileo who worked out the laws of falling bodies. All these did a great work, but Newton did a greater. His was the mind which generalized and saw unsuspected connections, connections which proved that the solar system was one. Newton's motto might have been *E Pluribus Unum,* for his discovery of the universality of the law of gravitation has been compared to that resolution of the Continental Congress for "a more perfect union." Indeed, the foundation of the law of gravity has been likened to the adoption of the American Constitution. By this instrument the states were unified, and all drawn towards the central seat of government, as are all bodies towards the sun. And as there was a balance of forces between the sun, earth and moon, so there was a balance of powers between the three branches of the government. No one of these can go out of its way to check the other, no one encroach on the other's orbit, but all are harmonious parts of a vast machine. In a word, Newton brought to his age a kind of federal universe whose parts formed a union one and inseparable.

§ 31. *The World a Divine Design*

Sir Isaac Newton's fame rests on the foundation which he made for the unity of the universe. For this view he gave the first facts. The Greeks had guessed it; Bruno had philosophized about it; Copernicus, Tycho, Kepler, and Galileo had each contributed mighty stones towards this foundation. Newton with his mathematical laws laid these in true courses and thus led men to the assurance that the universe was one and governed by uniform laws.

Now the stability of the system appeared so wonderful to Newton that it led him to believe that there was a reasonable Being who had arranged all things from the start. The world then became a divine design. If man may reduce the problems of celestial mechanics to mathematical laws this is because it is "God who geometrizes."

We have pointed out a kinship between Newton's unity of the universe and the formation of the American Union. There is another point of resemblance. Since the American Union has become "a more perfect union," since it has withstood the lapse of time and the shock of civil war, some highly patriotic people have come to believe that the Constitution was more than a human affair. Some have gone so far as to say that the "founding fathers" were led to construct the Constitution by divine guidance. So it was with Newton. What was called celestial mechanics worked so marvelously that it became celestial in the supernatural sense. So this argument arose: "If there is a machine there must be a designer, and if this machine works perfectly there must be a divine designer."

This is the famous argument for design. It had been in men's minds as a speculation for countless ages. Some of the Greeks held it, the medieval scholars reveled in it, and the astronomers of the Renaissance worked towards it. Now Newton brought forward fresh materials.

The problem of design was a lifelong interest with the Englishman. As a boy he had constructed little machines —windmills, waterwheels, and the like. At last he studied a world machine, a vast construction of countless parts, yet all working together. But where man's machines wear out, break down and need repairing, this world machine never wears out, never breaks down, and never needs repairing. The laws of nature are eternal. As far back as men have calculated, the heavenly bodies have run their appointed courses, always dependable, never tiring out. If a comet fails to reappear at the expected time, this is only because of some retarding force which men failed to take account of. If a comet breaks up, that is only because of the attraction of some stronger body. These failures and fractures are only apparent effects. They are really due to reasonable causes if only we knew all the causes. In short, all the order of the universe is due to an all-powerful order.

This view of Newton's became immensely popular. At a time when human governments were changing or decaying, the divine government of the universe was without fault. Newton made his first approach to the discovery of the law of gravitation in the year in which England suffered from a political revolution, when Cromwell overthrew the first Charles.

Besides change in England there was decay in France. Louis XIV was called the Sun King, but it did not need a telescope to discover that there were spots on that sun. Among the courtiers there was naturally a kind of professional sun worship, for they basked in the rays of royal favor. But with the people and peasants matters were different. The world went very well for those near the source of light, but for those far away life was dark and cold. The influence of the great central body reached the prince but not the pauper. The latter was repelled, and not attracted as he should have been. In a word, the French system of centralized government did not work in all its parts; it broke down at the edges, for its laws were not uniform for all. Now Newton's system was a contrast to all this. If human affairs are badly run, if the political machine breaks down, let man but look up to the celestial sphere where the laws are uniform, where no exceptions are made, in short, where harmony, heavenly harmony, prevails.

The argument for design ends in a great argument for optimism—of all possible worlds this is the best possible world, some went so far as to say. So this double argument had a great vogue. It was a fine source of comfort for those who lived in bad times, especially for those who saw or suffered the cruelties and injustices of their form of political government. This was one reason why Voltaire, the French critic, welcomed the Englishman's ideas and did all he could to make them popular in France. Just because he was a crabbed critic, a sour faultfinder, a pessimist at heart, he welcomed a system that might bring a little cheer. He highly approved of Newton's views that there is a divine purpose in the universe. Here he uttered his famous saying: "If there were no God, it would be necessary to invent Him." Yet he cannot go so far as Newton in believing in the particular as well as the general goodness of nature. After the destruction of Lisbon by an earthquake, he makes one of his characters say: "If this is the best world, what must the others be like?"

Problems and catastrophes like this show that it was hard to prove that the world machine was of divine design. Yet a long line of thinkers argued that it was. They began with the general and ended with the particular. Thus one of them reasoned that the Creator, being all wise, and pondering over the various world plans spread before his mind, would naturally choose the best possible plan. At the other end of the scale another reasoned that if any one thinks that there is no divine creation he should ponder over the intricate mechanism of the eye of a gnat, or the beautiful construction of a butterfly's wings.

But this kind of argument had another side. If the world machine down to its smallest details is quite perfect, does not this show that nature is self-sufficient? Perhaps nature can produce everything out of herself. It is even possible that matter itself is the source of all things. If it be indestructible, it must have existed from all time. And if matter can think—as the cautious Englishman Locke surmised—then the very plan and purpose of nature is merely the unfolding of what already existed. It takes time for the pattern to emerge, but the pattern was there as a potency or possibility. As an illustration, here is a Japanese toy, a box of pith balls, all of which look alike. When put into water these unfold into various forms. It may be a flower, or a fish, or a man. This is a symbol of what matter itself may do, so if nature is made of matter it may contain within itself all that exists or is to be.

This is the kind of argument that was directed against the view of the world as a machine of divine design. The opponents of that view granted that the world was a machine, but they held that it was of natural and not of supernatural design. Such is the view of the materialist who made not only the world a machine, but man a machine.

The Age of Mechanics that began with Galileo now came to bear its full fruit. Galileo applied his laws to terrestrial mechanics, Newton to celestial. But the pendulum swings back again to earthly bodies—this time not inanimate bodies like stones and cannon balls, but living bodies like men and animals.

BOOK IV

The Age of Mechanics

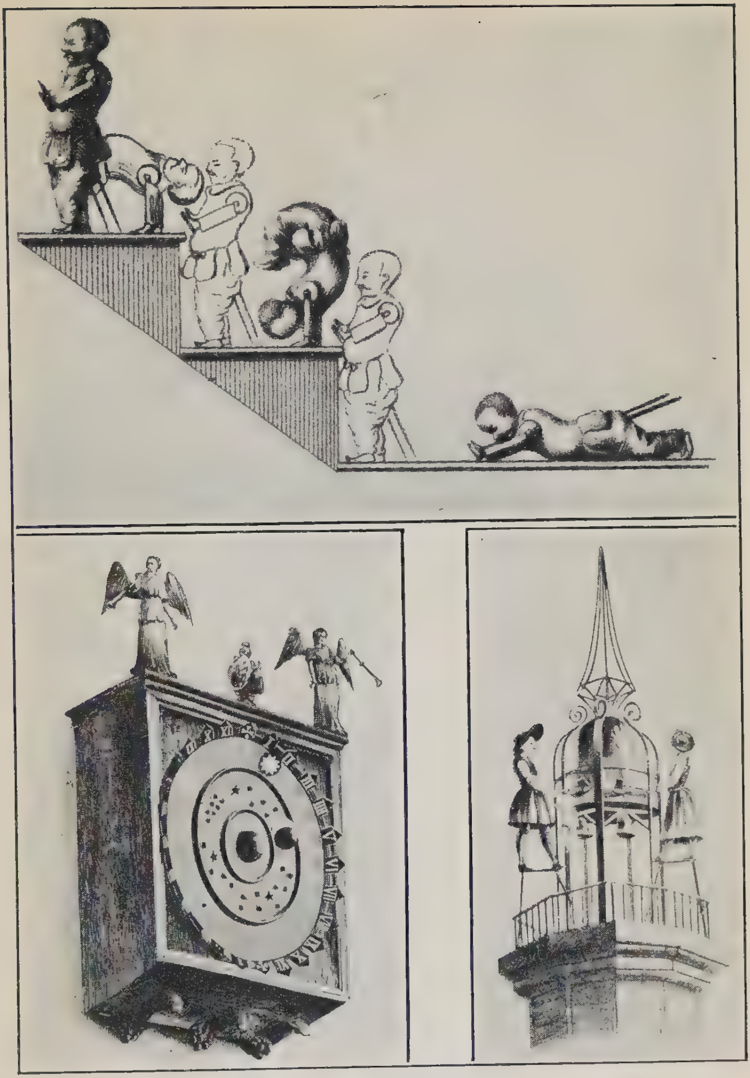
§ 32. *Man a Machine*

The idea of man as a machine keeps cropping up from time to time. A recent play has a stage full of these automatic creatures, made by machinery and themselves machinery. They look like men, act like men, and for all we know might be men, except they have no souls, and in an early stage, no feelings. But their maker, who stamped them out in his factory, found that without feelings they did damage to themselves. If they smashed their hands they felt no pain, and so great a loss of parts resulted from this that they had to be sent to the scrap heap. This did not pay, so the new models were endowed with nerves, and the result was that they reacted to pain and hurt and thus became more careful of themselves. They were capable of pleasure too, and when they came to find out that they were being deprived of the pleasures enjoyed by their masters and makers they revolted—with dire results to those who brought them into being.

The end of this play is not our concern, but the structure of the plot is. Fancy an animated statue, a mechanical chess player, a writing boy, a piano-playing girl, a manikin in a cave who tells his beads like a monk. Then imagine these made of various wheels, cogs, pulleys, bellows, tubes, and what not, and you have the beginnings of an idea that may explain living man as such. The French had this idea to a great degree, and several of their best thinkers carried it out into real life. It was an age of mechanical marvels, not only those just mentioned, but many others. There were subjects serious and frivolous, from a clock where the twelve hours were struck in succession by the twelve apostles to the water toys of Versailles, where in the famous gardens of the palace the unwary stranger who enters the grotto of the nymphs steps on a hidden plank and a sea god arises and squirts him with water.

This sort of thing logically carried out might explain man and his mechanism. One of these makers of mechanical marvels argued that, as he used more wheels for his flute player than for his quacking duck, so the driving works of a man are more complicated than those of animals. The person who really brought this notion into vogue was Descartes, the French philosopher. It is true that Tycho, the Danish astronomer, used to amuse the more light-minded among the visitors to his observatory and workshops with various performing puppets, but he reserved his celestial mechanism for the serious. Yet Descartes was serious enough, for he tried to show that the human puppets and the celestial machine were closely related. If the world is a machine, why is not man? They are both made of similar matter, both subject to similar laws; that which explains one will explain the other.

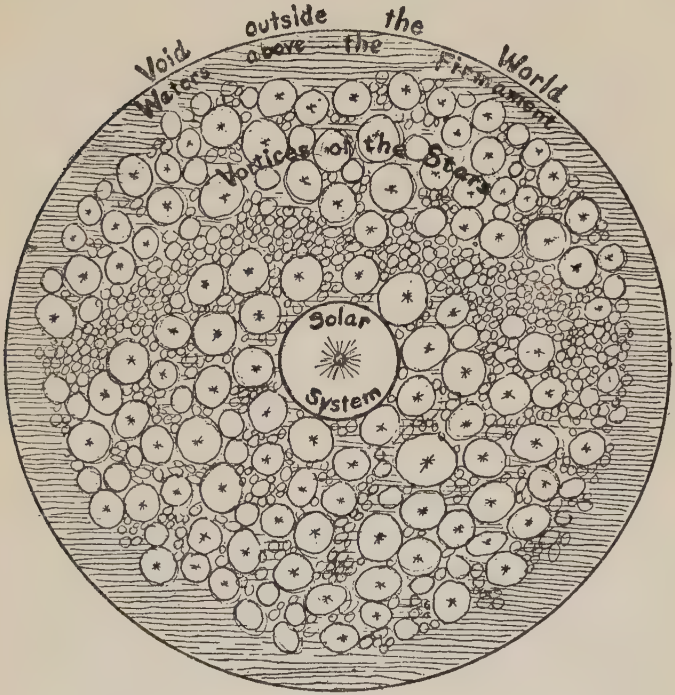
This was a bold question and at first sight a doubly dangerous doctrine. The very phrase "celestial mechanics" might mean that the heavenly bodies themselves were more under the guidance of mechanical laws than celestial beings—from angels who rolled the planets along to the creator "whose arm wound up the vast machine." And,



ANIMATED FIGURES

Above, a tumbling doll; lower left, the astronomical clock of Wimbourne; lower right, the steeple jacks of Dijon.

further, if man were a machine—a construction made up of tubes, valves, juices, animal spirits, and the like—what was the use of his possessing reason? If this mortal frame be all, whence came his immortal soul?



THE VORTICES OF DESCARTES

These were ticklish questions and the way Descartes answered them strikes us as a bit evasive. He had completed his book entitled *The World* and was ready to publish it when he heard of the condemnation of Galileo for teaching that the earth moves. The French philosopher had no desire to be confined to close quarters and have his mouth shut up by the Inquisition. So he made this compromise. Oh, no, the earth does not move itself, he explained. It only *is* moved. There are great vortices or whirlpools of matter which carry it about, as a log is rolled over and over by an eddy in a stream.

As for man as a mere machine, without guiding reason or immortal soul, that would be against the doctrines of the Church. But, says Descartes, I have no intention of teaching doctrines contrary to the Church. I merely suppose that if a man *were* a machine, with various tubes, valves, and animal spirits—that machine would act precisely in the way that man's body acts. In fact, most wise and illustrious doctors of the sacred faculty of theology in Paris, you yourselves could hardly tell the difference. Not that I want you to accept my views, but only that you might care to speculate over this ingenious theory.

But the wise and illustrious doctors were not taken in. Descartes' puppet people were dangerous toys, so even the revised edition of Descartes' book was suppressed and put on the index of prohibited works. But as usual this only whetted the curiosity of the clever, and the result was that Descartes' notion of man as a machine aroused the interest of a whole school of writers, who carried out this line of thought up to and beyond the French Revolution.

This general notion, without its early crudities, has persisted to this day. There is a modern school of biologists called behaviorists. These argue that living creatures, from polyps to people, behave thus and so simply because of the way in which they are constructed. If dogs delight to bark and bite so do men perform their various actions because "it is their nature to." The behaviorists are really old style mechanists. They bring in new things like protoplasm and chemical reactions. They have no more use for guiding reason and immortal souls than manufacturers of the modern "horseless carriage" have for dashboards and whipstocks.

§ 33. *The World a Machine*

Descartes' view of the world as a whole was a curious one. He wanted to be orthodox and he wanted to be original. He wished to avoid Galileo's dangerous doctrine of an earth which moves, and at the same time he did not want to go back to the ancient atomism. As he puts it, too many men hang on to old systems like ivy to the oak. So to meet these two conditions he invented a strange theory, that of vortices. The entire universe, he explained, is filled with whirlpools of subtle matter, and the path of the planets is to be explained by their being pushed from one whirlpool to another. Descartes' own diagrams trace out these paths by mathematical laws, and so far as mathematics goes Descartes was a master. But the original stuff itself is harder to explain. As pictured in the diagrams the universe looks as if it were made up of revolving ball bearings, some large and some small. Being balls there must be some spaces between the parts. These spaces are then filled up with splinters of the first matter, as a wall built of round stones has its cracks filled with rubble. In this way empty space was avoided. For Descartes, as a good churchman, had to hold to the belief that nature abhors a vacuum. All his opinions, he said, were submitted to the authority of the Church. Now the opposite of the absolute vacuum or emptiness is the plenum or fullness. Descartes obtained this by packing his universe with vortices and parts of vortices. Thus with the round bodies and their splinters he had a continuous mass of stuff without break or crack.

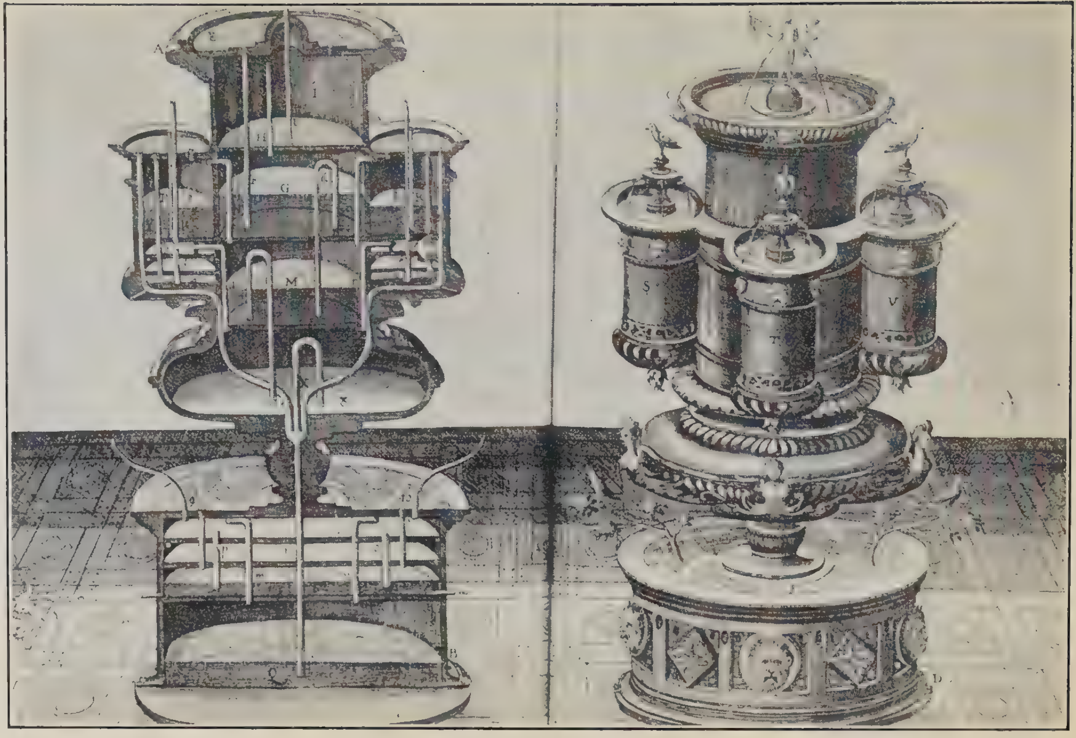
This seems an impossible view, unless we have in mind our present-day doctrine of the ether as a universally diffused substance, too subtle for the senses, too light to weigh or measure. This substance, say certain modern thinkers, like Lord Kelvin, is beyond ordinary knowledge, and so far not found to offer the slightest drag on our revolving world unless the recent experiments at the Mount Wilson Observatory hold true. Still, the ether, however far beyond the senses, must yet be assumed as existing within all things, as penetrating the pores of all matter, as present in the hollow tubes of barometer and thermometer, spread throughout space, and perhaps the source or ground of light, electricity, magnetism, and the like. Nowadays the ether, as used in the language of the radio experts, is supposed to bring about certain disturbances known as static troubles. In other words, the notion of a universe entirely full of matter, from the heaviest, most impenetrable metals to an almost unponderable or unweighable ether, has its upholders.

This will perhaps bring out the ingenuity of Descartes' views. The Copernican system as enlarged by Galileo's telescope had left an aching void in men's minds. There were terrific stretches of empty space which produced a feeling of being left alone in a desert. So Descartes' theory had quite a vogue. A lady in the French court who took up with Descartes' system is said to have remarked, "I adore vortices." In England this theory made headway in the universities and was the accepted thing when Newton went to college. But the discovery of the law of gravitation seemed to give the death blow to the scheme, for it was finally determined that the attraction between the sun, earth, and other heavenly bodies acts through empty space. So Descartes' vortex universe fell from fashion, only to be revived in another form in modern times. Since the atom has been split into electrons it is supposed that the latter may consist in part of etherial whirls—tiny ghosts, as it were, of Descartes' great vortices in which the planets swam.

Descartes' vortical world machine broke down even in his day. But his theory of man as a machine lived on. It was not based so much on speculation as on observation. When he retired to Holland, where there was more freedom of thought than in the France of his day, he took up anatomy. We are familiar with Dutch pictures of anatomy classes and of dissected animals. Descartes himself took much interest in these subjects. When a friend once visited him he found him busy with a scalpel over the head of a calf. This was no idle task, for later on he made the conjecture that perhaps, if men's skulls were greatly enlarged, one might walk through them and see the machinery work as it does inside a Dutch windmill.

Now when Descartes discourses on the proper method of finding how man is a machine, he makes this suggestion:

> So that there may be less difficulty in understanding what I shall say on this matter, I should like that those not versed in anatomy to take the trouble, before reading this, of having cut up before their eyes the heart of some large animal which has lungs (for it is in all respects sufficiently similar to the heart of a man) and cause that there be demonstrated to them the two chambers or cavities which are within it.



SIXTEENTH-CENTURY MECHANICAL FOUNTAIN WITH ANIMATED FIGURES

Without going into a lesson in anatomy, we find that Descartes argues that man is here built like a machine with tubes and valves, through which passes a fluid, the blood, just as water through a pump. This trite knowledge was a new thing to Descartes. He gained it from the English surgeon Harvey, who discovered the circulation of the blood and compared the heart to a water ram, the pulse being like the clack of that machine. Following Harvey, then, Descartes does not doubt that all the veins and arteries of the body are like streams by which the blood ceaselessly flows from the right cavity of the heart through the body and finally back into the left cavity. Thus the two cavities are like sluices through each of which all the blood passes in the course of each circuit which it makes in the body.

All this brings up the familiar Dutch landscape. When Descartes looked out of the window of his hermitage he could see the mills with their pumps, and the dikes with their sluices that kept the water in circulation. But these are artificial, some may object, while man's body is a work formed by the Great Artificer. "Granted the latter," replies Descartes, "I can see no difference between bodies made by art and natural bodies, excepting that machines made by men have parts large enough to be perceived by the senses, whereas the effects of natural causes depend on certain organs minute enough to escape every sense."

The microscope was not yet available to Descartes, but he reasoned rightly that the laws of mechanics hold true in the most minute parts of natural bodies, or putting it the other way, all that is artificial is also natural. It is no less natural for a clock, made of the requisite number of wheels, to indicate the hours, than for a tree, which has sprung from this or that seed, to produce a particular fruit. Accordingly, just as those who apply themselves to the consideration of an automaton, when they know the use of a certain machine and see some of its parts, infer from these the manner in which others which they have not seen are made, so from considering the sensible effects and parts of natural bodies, he endeavored to discover the nature of the imperceptible causes and insensible parts contained in them.

Here Descartes was pursuing what he calls the search after truth by means of the light of nature. This, he declares, without the assistance of religion or philosophy penetrates into the secrets of the most curious of the sciences.

§ 34. *Anatomy and Machinery*

The science here considered is anatomy. By the study of this Descartes would prove that man is an automaton. As this science was then in its infancy, and as the microscope was not yet in general use, many of the views put forward sound more medieval than modern. Descartes had just been describing the circulation of the blood and the functions of the heart. To the question: "What is the principle of all these functions?" he answers:

> We know that all these movements of the muscles as also all the senses depend on the nerves, which resemble small filaments or little tubes, which all proceed from the brain, and thus contain like it a certain very subtle air or wind, which is the animal spirits.

All this, at first sight, might seem a forecast of a modern engine run by compressed air. It is really nothing but the revival of the medieval and even ancient belief that the animating principle of man is a subtle form of warm air. We still have an echo of this ancient idea when we say that people are "full of animal spirits." But the old view had also a touch of alchemy in it. Just as spirits were distilled in a retort, so here the heart, perhaps because of its shape, also became an alchemical retort. As Descartes describes it:

> So long as we live there is a continual heat in our heart, which is a species of fire which the blood of the veins there

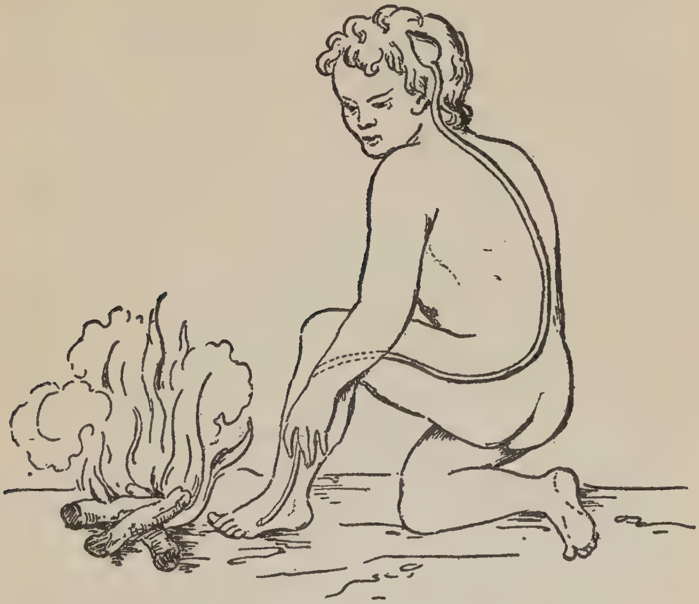
maintains, and this fire is the corporeal principle of all the movements of our members.

But the process of distillation is not yet complete. Besides the heated retort there must be a cooling chamber. This is the function of the brain—a strange notion borrowed from Aristotle and still reflected in the phrase, "Keep your head cool."

This, then, according to Descartes, explains how the animal spirits are finally produced in the brain. All the most animated and subtle portions of the blood, which the heat has rarefied in the heart, enter ceaselessly in large quantities into the cavities of the brain. And because there are only very narrow passages there, those of its parts which are the most agitated and the most subtle alone pass through, while the rest spreads abroad in all other portions of the body. . . . Now what are here named spirits are nothing but material bodies and their one peculiarity is that they are bodies of extreme minuteness and that they move very quickly like the particles of the flame which issues from the torch.

All this argument may appear fantastic after the lapse of three hundred years. But so may the view that some hold nowadays that life is electricity and man an electrical machine—after the lapse of an equal period of time.

Descartes has now put forward his creed. It is that man is a machine run by that which is very subtle matter, but still matter. From this it follows that all the bodily members may be moved by the objects of the senses and by the animal spirits without the aid of the soul. For example, the machine of our body has pores. When these are opened by heat as the stimulus, they affect the animal spirits, which in turn affect the nerves and muscles. Here is a small boy kneeling by a fire. Particles of the flames open his pores, these convey the message of heat by the nerves to his brain, these affect the animal spirits, the animal spirits affect the muscles, and these finally cause the boy's foot to be withdrawn from the vicinity of the flame.



DESCARTES' CONCEPTION OF THE CAUSE OF REFLEX ACTION

So much for reflex action, where the movements of the body are more or less unconscious and involuntary. Descartes here gets rid of the so-called sensitive soul. In this way he explains all the movements which we make without our will contributing thereto, such as frequently happen when we breathe, walk, eat, and in fact perform all those actions which are common to us and to the brutes. These only depend on the conformation of our members, and on the course which the spirits, excited by the heat of the heart, followed naturally in the brain, nerves, and muscles, just as the movements of a watch are produced simply by the strength of the springs and the form of the wheels.

But so far and no farther. Descartes got rid of the so-called sensitive soul, he did not dare discard the rational soul. Hence he goes on to say that while we can explain mechanically all the functions which pertain to the body alone, yet we ought to attribute to our soul our thoughts. Here is a distinction. Is there really any actual difference from what went before? The soul is still dependent on the machinery of the body. Thus when we see the light of a torch and hear the sound of a bell, this sound and this light are actions which, simply by the fact that they excite two different movements in certain of our nerves, and by these means in the brain, give two different sensations to the soul. These sensations we relate to the subjects which we suppose to be their causes in such a way that we think we see the torch itself and hear the bell, and do not perceive that our sensations are due to the movements which proceed from them.

In this passage Descartes, perhaps purposely, makes a very poor defense in behalf of the rational soul. He practically says that it really does not know, but that it only *supposes* or *thinks* that outside objects like a torch or a bell exist. In other of his works he gets over this by saying that: "Since God has been so good as to give us a soul, He would not allow our senses to deceive us." But here in his treatise on man as a machine Descartes really turns the soul into a part of the bodily machine. He is indeed hard put to it to locate the seat of the soul, for he mentions some curious cases, as where a soldier with an amputated leg still felt pains in his lost foot. From this he argued that the seat of the soul is in the brain, but in what part is the problem. The brain is built in two halves; if both were affected we ought to see two roses when we look at one, feel two bullets when we touch one. This is a puzzle. To solve it we are forced to conclude that the seat of the soul is single. Now in the brain there is a curious part which has no counterpart—a small gland called the pineal gland. This, he concludes, is the part in which the soul exercises its functions more particularly than in other parts.

This of course is wrong. There is a gland called the pineal gland, but it is what is known as a vestigial remnant—a discarded organ which once had a use, perhaps as a reptilian eye in the top of the head. However, with the imperfect knowledge of his day Descartes is ingenious in finding a function for this gland. As the seat of the soul it is the location of "common sense." As we might say in these days of the telephone, it is "central" to which all messages go to be relayed elsewhere. As Descartes represents it in his diagrams this little pear-shaped gland has various movements caused by the stimuli from outside, the meanings of which are interpreted by the soul. Furthermore the gland inclines first one way and then another and directs the animal spirits to different parts of the brain through various pipes, just as currents of air are distributed in a pipe organ.

Why does Descartes drag in the soul in this scheme of his? It is in order to be on the safe side, for the Church demanded that the rational soul should be preserved. But like his pineal gland, Descartes' opinions seemed to turn first one way and then another. At one time he argues that this machine of his imitates so perfectly the human being as he is, that one might as well accept it as a substitute. But naturally Descartes knew that the Church would accept no such substitute. So he sets to arguing on the other side. He explains that we can easily understand a machine's being so constituted that it can utter words. For instance, if it is touched in a particular part, it may ask what we wish to say to it; if in another part, it may exclaim that it is being hurt. But, he adds, while reason is a universal instrument which can serve for all contingencies, these organs have need of some special adaptation for every particular action. From this it follows that it is morally impossible that there should be sufficient diversity in any machine to allow it to act in all the events of life in the same varied way that our reason causes it to act.

By all this, Descartes goes on to say, we may recognize the difference that exists between men and brutes. It is not the want of organs that brings this to pass, for it is evident that magpies and parrots are able to utter words just like ourselves, and yet they cannot speak as we do, that is, so as to give evidence that they think of what they say. . . . The fact that they do some things better than we do, does not prove that they are endowed with minds. It rather shows that they have no reason at all, and that it is nature which acts in them according to the dispositions of their organs, just as a clock, which is only composed of wheels and weights, is able to tell the hours and measure the time more correctly than we can do with all our reason.

§ 35. *Man a Machine with Feelings*

Descartes left behind him two views, each of which had two sides. One concerned the world as a machine, the other man as a machine. In his world made up of vortices, or whirlpools of matter, he set out to explain the movements of the parts of the universe. The planets move about the sun as do boats in eddying streams; so with meteors, comets, and other heavenly bodies. All this he called a description of a new world and of the qualities of matter of which it is composed. The laws of this new world, he added, furnished a better explanation than the laws of cycles and epicycles put forward by Ptolemy. But before he published this *Treatise on the World* he learned with dismay of the punishment of Galileo for propounding a system contrary to that of Ptolemy. Descartes is astonished. He writes to a friend:

> I could hardly have believed that an Italian, and in favor with the Pope, as I hear, could be considered criminal for nothing else than for seeking to establish the earth's motion. . . . I confess that if the opinion of the earth's movement is false all the foundations of my philosophy are so also, because it is demonstrated clearly by them. It is so bound up with every part of my treatise that I could not sever it without making the remainder faulty; and although I consider all my conclusions to be based on very certain and clear demonstrations, I would not for all the world sustain them against the authority of the Church.

Descartes need not have worried. His world machine whose motive power was vortices did not last long. It was almost at once superseded by Newton's discovery of the law of gravitation. Part of it was later salvaged from the scrap heap when the nebular hypothesis of another Frenchman, Laplace, came in. Whirling clouds of star dust out of which suns were formed did serve to explain some things in the universe, and so the vortex ring was partially revived.

But Descartes' other pet scheme fared better. The notion of man as a machine had a great vogue and it is still held by many. Descartes hardly dared put it on the market stripped of its accessories, but others did. By keeping the guiding reason and the immortal soul he thought to disguise the horrid machinery within. His more thoroughgoing successors had no use for these appendages.

For a time the notion of a body machine was applied only to animals, and this led to strange results. Descartes said that reflex action could be explained without the intervention of the soul. When a friend pokes a finger at my eye, just for fun, the eye closes quicker than I can think, for really I do not think. Now apply this to the brutes, without any souls, and monstrous conclusions can be drawn. Dogs, for example, are mere automata. So when a certain Cartesian, or follower of Descartes, was upbraided by a friend for kicking a poor hound he replied that his treatment of the dog did not matter, as brutes have no feelings.

So a correction was made. No society for the prevention of cruelty to animals was responsible for this, but only those who thought that the Cartesians were not thorough enough. If animals are machines, why not men? But men feel, retorted those who believed in the sensitive soul. Well, then, make matter feel, countered the materialist, and you get rid of the sensitive soul—that fifth wheel of the human machine. The old-fashioned thinkers who put animal and human in two separate and different kingdoms did not like this. They were sticklers for class distinctions. But there are no such distinctions, argued the radicals. A dog howls for the same reason that an unthinking infant howls. It is because it is hurt. Each has a similar nervous system, and nerves are made of matter, and matter is sensitive. You are reasoning in a circle, replied the high and mighty believers in spiritual substance. No, replied the materialist, we have very good authority for our statement. The ancients put a kind of feeling of affinity into the atom. A great modern philosopher, John Locke of England, has gone so far as to say that, for all he knew, God might have endowed matter with thought. Now if matter can think, much more can it feel, for feeling is a lower form of thinking, just as thinking is a higher form of feeling.

All this explains the next step taken in the progress of the idea of man as a machine. It corresponds to that part of the play already mentioned where the author was obliged to put feeling into his mechanical characters, lest they should smash their fingers and other parts of their anatomy. In Act I they have no feelings; in Act II the concern which manufactures these automatic workmen finds that it pays to furnish them with a nervous system.

Now the natural philosophers of the eighteenth century did the same thing. They declared that living creatures are not mere machines, but sensitive machines. Their motto was: "From Polyp to Prince all is but Pain and Pleasure."

§ 36. *Man a Sensitive Machine*

Descartes had made much of the soul. He said it was more easily known than the body. It might be confined to the brain, but it ruled the brain as a king ruled his kingdom. The materialist said that such a ruler was a do-nothing king, an empty husk, a mere name, a ghost of a pious idea. The body as a living machine had no more use for a soul than a clock needs the principle of horologity or clock-ness to make it go. It goes because it is built of material parts and is wound up. In the case of the animal machine there is no winding up of weights or springs because its matter is alive and contains its own principle of motion. Of course it may stop never to go again, but this is only because of some very bad injury or entire breakage. But in slight injuries the living machine may repair itself. A cut finger, left to the healing powers of nature, heals itself. In lower organisms this goes further. A starfish is torn apart, it does not die, but each ray or limb forms a new starfish.

But further, the wonders of nature are great because matter is wonderful. Its powers seem miraculous, if you want to keep that old-fashioned word. At any rate it is astonishing what matter can do. The seed sprouts and turns into a plant, bears new seeds, and these in turn new plants. A caterpillar goes in a deep sleep, becomes torpid and unconscious. Then through the chrysalis it emerges a butterfly. This in turn lays eggs which hatch into caterpillars which go through the old process, and thus the immortal cycle keeps on.

The materialists were accused of turning their gaze downward towards the earth, of being mere stupid clods like the matter of which they made so much. But just as the worm will turn, so did they. They retorted: You worshipers of abstract spirit and empty principles lift your eyes so high that you do not see the wonders at your feet. Material nature, which you despise, is a constant miracle—if you care to use that word. It is a storehouse of bright treasures more valuable than your moss-covered traditions.

This was a strange state of affairs. The despised materialists turned out to be a band of worshipers and furnished the very creed for the coming religion of nature. So the study of the natural sciences on the part of the materialists and so-called atheists led to a new cult and a new band of worshipers, from an enthusiast like Jean Jacques Rousseau to a sentimentalist like the author of *The Swiss Family Robinson.*

This is the first chapter in that curious romance which might be called "Mother Nature, the Kindly Nurse of All." We have not yet reached the end of this romance. Much is still written that makes nature bountiful, beneficent, ever faithful to the interests of man. The modern scientist, however, has a great deal to say to the contrary. From the Arctic to the Tropics he could give the sentimentalist much to think about—cold and frost, cyclones and tornadoes, mosquitoes and malaria, rats and bubonic plague, all these read more like a Newgate calendar of crimes than a list of Christmas presents to Mother Nature's favorite child—Man.

But to go back to the people who started this sort of romance and fiction. They began as cynics and not as sentimentalists. The foundation of their belief was that all that exists may be traced back to matter; that matter and motion would explain everything that happens. Thomas Hobbes, for example, declares that all sensations could be explained by "the perpetual propagation of pressures." By this neat phrase he meant that pressures, or waves of air, light, and so forth, made vibrations on the nerves and these in turn were carried to the brain. When the brain vibrated, sensations arose, and out of these came sense impressions or ideas. For example, when through various channels of sense I receive a perception of redness, roundness, sweetness, and so on, I obtain the idea of an apple.

This explanation perhaps impressed the brain of Hobbes more than it does ours. As a description it may pass; as an explanation it leaves a great deal to the imagination. It is like asking us to believe that a certain "spirit photograph" was developed in a dark room and at the same time not allowing us to enter the dark room to see what tricks are played. But in spite of all this the English vibration-sensation theory met with a great success. Voltaire brought it over to France and the French fell on it and thought it was the finest tidbit in the world. They next tried it with new sauces of their own mixing and gave such a relish to it that the public seemed never to have enough. We could give a long list of the new chefs—La Mettrie and Holbach, Diderot and Condorcet, Helvétius and Cabanis, and many others. It is interesting to know that Thomas Jefferson when Minister to France tasted of their viands and was quite taken with them. After meeting the last two of the men on this list he declared: "I am a materialist, I am a sensationalist"—though later he changed his opinions and seemed to prefer the home cooking of the common-sense school.

§ 37. *Man a Self-Regulating Machine*

Descartes, we recall, had written a book entitled *Man* and left the reader to infer that man was nothing but a machine. This was quite logical, because the soul, as described in this work, seemed a mere ornament. It was like a false window on a house; open up the shutters from outside and there is nothing but a blank wall. Descartes indeed tried to keep the soul by giving it the job of moving the pineal gland, that little trapdoor in the attic of the brain. But this, argued the materialist, really leaves the body a soulless machine. If the body contains its own motions, or is supplied with them from outside bodies, then matter plus motion will explain the whole thing. It is like the steam engine of a later day. The speed of Watts' machine was controlled by a boy who pulled a string. The boy was clever enough to discover that if the string were tied to a certain part of the mechanism, the engine would regulate itself. So with the body-machine. It regulates itself by its own mechanism.

It was the Frenchman La Mettrie who brought this out clearly. Man, he explained, is so complicated that it is impossible to get a clear idea of the machine beforehand, and hence impossible to define it. Yet we can say that the human body is a machine which winds its own springs. It is the living image of perpetual motion. Let us now go into some detail concerning these springs of the human machine. All the vital, animal, natural, and automatic motions are carried on by their action. Is it not in a purely mechanical way that the body shrinks back when it is struck with terror at the sight of an unforeseen precipice, that the eyelids are lowered at the menace of a blow, as some have remarked, and that the pupil dilates to see objects in darkness? Is it not by mechanical means that the pores of the skin close in winter so that the cold cannot penetrate to the interior of the blood vessels, and the stomach vomits when it is irritated by poison, by a certain quantity of opium, and by all emetics? That the heart, the arteries, and the muscles contract in sleep as well as in waking hours, that the lungs serve as bellows continually in exercise . . . that the heart contracts more strongly than any other muscle?

But beside these little subordinate forces, well-known to all, there is another more subtle and marvelous force which animates them all; it is the source of all our feelings, of all our pleasures, of all our passions, and of all our thoughts, for the brain has its muscles for thinking, as the legs have muscles for walking. Look at the portrait of the famous Alexander Pope who is, to say the least, the Voltaire of the English. The effort, the energy of his genius are imprinted upon his countenance. It is convulsed. His eyes protrude from their sockets, the eyebrows are raised with the muscles of the forehead. Why? Because the brain is in travail and all the body must share in such a laborious deliverance. If there were not an internal cord which pulled the external ones, whence would come all these phenomena?

Is more needed to prove that man is but an animal, or a collection of springs which wind each other up, without our being able to tell at what point in the human circle nature has begun? If these springs differ among themselves, these differences consist only in their positions and in their degrees of strength, and never in their nature; wherefore the soul is but a principle of motion or a material and sensible part of the brain, which can be regarded, without fear of error, as the mainspring of the whole machine, having a visible influence on all the parts.

La Mettrie proceeds to demonstrate that the human body is like a watch, a large watch constructed with such skill and ingenuity that if the wheel which marks the seconds happens to stop, the minute wheel turns and keeps on going its round, and in the same way the quarter-hour wheel and all the others go on running when the first wheels have stopped, because rusty or, for any reason, out of order. Is it not for a similar reason that the stoppage of a few blood vessels is not enough to destroy or suspend the strength of the movement which is in the heart as in the mainspring of the machine; since, on the contrary, the fluids whose volume is diminished, having a shorter road to travel, cover the ground more quickly, borne on as by a fresh current which the energy of the heart increases in proportion to the resistance it encounters at the ends of the blood vessels?

The French materialist has proved, at least to his own satisfaction, how wonderful a machine is man. It goes by itself, shifts gears by itself, and now he can show that even the parts run by themselves. To prove this he must descend to animals. Since they are machines the proof holds good. So he adds that the flesh of animals, such as tortoises, lizards, and serpents, palpitates after death; that a frog's heart moves for an hour or more after it has been cut from the body, and that a rooster with its head cut off runs about for a time.

The critics might retort that this merely proves that animals are machines and this they would be willing to grant because Descartes really left animals without souls or sensations. The out-and-out materialist must then put man and animal in the same class. He does so when he declares that there is but one type of organization in the universe, and that man is merely the most perfect example of this type. He is to the ape and the most intelligent animals as a fine watch is to a pendulum clock. If you object that animals, for the most part, are stupid automata run by blind instinct, savage beasts incapable of realizing the evil that they do, turn and consider men. For truly, up to a certain age, he is more of an animal than they, since at birth he has less instinct. What animal would die of hunger in the midst of a river of milk? I will grant, says La Mettrie, that animals, even the best of them, do not know the difference between moral good and evil. But there is ferocity in our species as well as in theirs. The combat of man against man is more inhuman than one could find among lions, tigers, and bears put together. For our compatriots fight, Swiss against Swiss, brother against brother, recognize each other and yet capture and kill each other without remorse, because a prince pays for the murder.

La Mettrie is certainly a clever debater, for he hits right home. He writes from Geneva, famous for its watches, from Switzerland which furnished mercenaries to the French King, and uses these two facts to prove that animals are machines as well as men, and men beasts as well as animals. As he puts it: Man is not molded from a costlier clay; nature has used but one dough, and has merely varied the leaven.

This language was at once seized upon by his adversaries. The anti-materialists said that this talk about our common clay turns the soul not merely into a soul of clay, but a soul of dirt. Materialism is a dirt philosophy, degrading to man, abhorrent to higher reason.

This, it may be noted, is the same argument that is brought forward nowadays by the anti-evolutionists. They can see no connection between monkey and man, or rather between these two creatures and a common "missing link." They say it is insulting to the intelligence to reason that they come from the same stock, that it is monstrous even to suppose that there was a remote primate, the common ancestor of a Shakespeare and a specimen in the zoo.

La Mettrie, the first and boldest of the modern materialists, certainly raised a disturbance, but he was defended by his patron, the sarcastic Frederick the Great. As a physician in France he had been appointed surgeon of the guards; he had also published his book, *Man a Machine,* in Holland. With these two facts in mind the Prussian monarch made the following remarks in his eulogy of La Mettrie:

> The author underwent a frightful persecution and the priests claimed that a doctor accused of heresy could not cure the French Guards. . . . So La Mettrie, after losing sight of his hospitals and his patients, gave himself up completely to speculative philosophy and wrote his *Man a Machine.* This work, which was bound to displease men who by their position are declared enemies of the progress of human reason,

roused all the priests of Leyden against its author. Calvinists, Catholics, and Lutherans forgot for the time that consubstantiation, free will, masses for the dead, and the infallibility of the Pope divided them: they all united again to persecute the philosopher who had the additional misfortune of being French, at a time when that monarchy was waging a successful war against their High Powers.

§ 38. *The System of Nature*

La Mettrie had a lively defender in Frederick the Great. But in spite of the royal patron society generally turned against the author. Even before his death his enemies were upon him. The last straw was his writing a book entitled *The Natural History of the Soul.* Imagine, they exclaimed, the natural history of a supernatural object! The very chaplain of the regiment of which La Mettrie was physician sounded the tocsin against him. However, as the Prussian monarch goes on to say:

> The common ecclesiastic is like Don Quixote, who found marvelous adventures in commonplace events, or like the famous soldier, so engrossed with his system that he found columns in all the books he read. The majority of priests examine all works of literature as if they were treatises on theology, and filled with this one aim, they discover heresies everywhere. To this fact are due very many false judgments and very many accusations, for the most part unfair, against the authors. A book of physics should be read in the spirit of a physicist; nature, the truth, is its sole judge, and should be read in the same manner. If a poor physician proves that the blow of a stick smartly rapped on the skull disturbs the mind, or that at a certain degree of heat reason wanders, one must either prove the contrary or keep quiet. If a skilful astronomer proves, in spite of Joshua, that the earth and all the celestial globes revolve around the sun, one must either calculate better than he, or admit that the earth revolves.

Yet even the free-thinking Frederick could not follow La Mettrie's followers. One of these was Holbach. Born in Germany, educated in France, this wealthy baron became the center of the new school, a school so radical that it became a scandal. Even the cynical Voltaire could not stand it. Out-and-out materialism, he declared, led to atheism, and atheism, he added, is the most narrow view held by the reason. It is as ridiculous to say that the arrangement of the world does not prove a supreme artisan as to say that a watch does not prove a watchmaker.

This sort of reasoning appears rather strange in the mouth of Voltaire, the skeptic. Yet while popularly believed to be an atheist, Voltaire had a place for a God in his system, just as he had a place for a chapel on his country estate. This God was an artisan, indeed, but not an all-powerful artisan. Just as a workman is hampered by poor materials so the Creator is hampered by matter itself.

Now extreme materialists did not stop with this half-and-half view. They boldly said: "Leave out God, the do-nothing King of Heaven. Leave everything to matter because matter can do everything. It crystallizes in the mineral, is sensitive in the plant, feels in the animal, and reasons in man. Why it does this nobody knows. It does it, that is enough."

Such indeed is the message of the *System of Nature,* which made as much of a sensation in the eighteenth century as Darwin's *Origin of Species* in the nineteenth. Holbach did not dare to publish this book under his own name. His other books had been burned by the public hangman, and those who peddled them were put in the pillory, scourged, branded, condemned to the galleys. The book therefore was fathered upon Mirabeau, the perpetual secretary of the French Academy, and printed by express order of the King. This authorship was pure fiction, as was the story that the manuscript was Mirabeau's last will or testament of belief for the benefit of posterity.

By getting another to be his press agent, Holbach succeeded in publishing his own system. And what a system it was! This "Bible of Scientific Materialism," as it was called, declared for the self-existence of matter and for the possibility of deriving everything from matter. From matter in motion come all the events that strike our senses. All is matter or a function of it. Matter itself is not an effect, but a cause. It is not caused, but is its own cause, for it is from eternity and of necessity. It therefore needs no creator. Matter being eternal and necessary and the cause of all things, nothing therefore is outside the laws of physics and chemistry. Minerals, plants, animals, men—all are results of matter and motion. If man affirms that he has free will and an immortal soul apart from his machine, that is idle talk. Still more idle is it to speak of a world-soul animating all. In one word, theology, or poetry about God, as Petrarch said, is ignorance of natural causes reduced to a system.

Such is the *System of Nature* which went through some thirty editions in Europe and America. It was famous because it was counted infamous. It came out in 1770, just before the revolutionary period in the two continents. It was the first rumble of the storm which cleared the air for some and brought ruin to others. To say the least, the book was radical. If men believe in ideal powers, in imaginary intelligences, says the author, let them now get rid of them. They make nature capricious, unexplicable, useless for the happiness of man. The chief cause of man's misery, of his lack of well-being, is his ignorance of the powers and possibilities of his own nature and of universal nature. Instead of calling upon supernatural powers, his best plan is to find out his place in nature and adjust himself to it. If ignorance of nature gave birth to the gods, knowledge of nature is calculated to destroy them and the evil resulting from belief in them. In a word, truth, that is, correct ideas of nature, is the one thing needful to the happiness and well-being of man.

We can easily imagine what a stir was raised by this so-called "Bible of Materialism." Holbach himself was a delightful personality and his house a kind of philosophical inn for people with new ideas. But we fancy he must have been a social porcupine to others, for the darts he threw off punctured the skins of many. The conservative clergy, the moderate philosophers, the respectable members of society considered him a pest. Cries of irritation and pain arose. Many said that the *System of Nature* undermined both Church and State, in a word, that it was nothing but atheism "accommodated to chambermaids and hairdressers."

It is likely that Holbach's attacks did partially undermine the Church. He was in the van of those natural philosophers who did all they could to prove that religion was a fiction and a fraud. Thus Voltaire held that Holbach went too far, yet even he himself suggested that "if there were no God, it would be necessary that we invent one." To Voltaire religion was a useful fiction, a kind of moral police to keep the common people in order.

Beside such a fashionable skeptic as this there was the vulgar skeptic like Thomas Paine, author of the *Age of Reason.* The latter declared that religion was not only a fiction but a fraud, a scheme concocted by the priests, "for pence and power."

The *System of Nature* and its countless imitations certainly did much to undermine the Church. Instead of the worship of supernatural powers there came the worship of natural forces. In the minds of the revolutionaries the Bible, the Holy Book, was supplanted by the Book of Nature. There were to be no more miracles, no more divine interferences, but all was to be explained in terms of iron necessity.

Such was the message of the so-called "Age of Reason," the revolutionary period when altars and sacred images were replaced by the "Altar of Reason" and the "Goddess of Reason." What went on in Paris in the days of the Terror was reflected even across the Atlantic. A Jacobean society was started in Virginia; a festival of reason was held in Philadelphia. In New York a popular picture represented the Book of Saints and the Ten Commandments as being dashed to the ground from the Altar of Truth and Justice.

The system of nature as set forth by Holbach and his disciples tended to undermine the Church. Did it undermine society, as was also charged? It certainly did, from the conservative point of view. The aristocrats who looked down upon chambermaids and hairdressers must have read with dismay a passage like this: "As government only derives its powers from society, and is established only for its good, it is evident that society may revoke this power when its interests demand, may change the form of government, extend or limit the power entrusted to its leaders, over whom it retains the supreme authority, by the immutable law of nature that subordinates the part to the whole."

All this has a familiar ring. Written in 1770 it is almost the language of the Declaration of Independence which announces that government derives its just powers from the consent of the governed. But this is going too far afield. *The System of Nature* runs off into human nature, but it is the world more as a mere machine than as a political machine that we are now considering. Here the *System*, as it was simply called, brought about a strong revolt among the more moderate thinkers. To derive everything from matter, to say that matter plus motion explained even the process of thinking, to make man nothing but a machine, outraged some and did not convince others. God, freedom, immortality, the soul, goodness, beauty—a whole set of ideas would be swept away by this scheme. And beside these matters of sentiment there were questions of science which men could not square with the *System of Nature*. Granted the existence of matter and motion, do they explain everything? Why is there order in the universe, why laws according to which matter and motion act? These were the questions which materialism did not explain, these were the questions that brought about the real revolt against materialism.

§ 39. *The Revolt against Materialism*

Man a Machine and *The System of Nature* were the two most famous books of the eighteenth century to present the materialistic view of the world. They attempted a revolution in thought, in turn they met with a counter-revolution. Here there were two classes of critics. There were the supernaturalists who wished to preserve matters of sentiment, such as the belief in Deity, freedom and immortality. There were also the naturalists who wished an answer to matters of science. Man may be a machine, but does that explain him as a thinking being? The world may be a mechanical system, but does that solve its law and order?

It is of course not possible to keep these two classes perfectly distinct. Sentiment and science, faith and reason, are like the lobes of the brain—when one does not work the other may sometimes take up its function.

Science and reason, then, began to make such objections as these: When you compare men to mechanical toys you are going back to the nursery. In Paris there may be a figure in a grotto that tells his beads like a monk; in Venice there may be a clock where two giants strike the hours with their hammers. These things are interesting to observe, but they do not explain. Man is more than a manikin, just as an animal is more than an automaton. If you reply that man is a thinking machine, and an animal a machine that feels, what do you mean by thinking and feeling? You say that as a violin string vibrates and gives forth sound, so the brain fibers are stimulated to render or repeat the words that strike them. You also say that judgment, reason, and memory are merely modifications of the brain screen upon which images and objects painted on the eye are projected as by a magic lantern.

We will not reply that these are mere long words of description, for description is valuable. The brain fibers do vibrate, or at least have some sort of motion; the eye is somewhat like the lens of a magic lantern and obeys the laws of refraction. But is description the same as explanation? The violin string vibrates, but does it feel? The brain screen, in a way, "reflects," but is this mental reflection? In short the mystery of matter raises the further mystery of feeling and thought. For all your clever comparisons you have not reached the final answer.

Put in a more modern way, these materialists have employed mechanics, but they have left out psychology. They talk of lines of force; they say that where those from outside the body cross those from inside of the brain there arises consciousness. Now it has taken a long time to invent a machine which can tie a knot, but no farmer would say that his self-binder is conscious of tying a knot.

The old style materialist did a great service in describing both the forms and functions of the animal machine, the human machine, and the world machine. Yet they did little to explain how those forms, or molds, or models, or plans, or structures got inside matter.

This is the real mystery of matter, perhaps never to be solved. But some explanation is better than none. Human curiosity is not satisfied by taking a thing for granted. It likes to know how a thing is built; it also wants to know why a thing is built thus and so.

But, replied the materialists, this is the search for final causes. If we know the means—such as pulleys and ropes, valves and tubes—why worry over the ends? See what the speculative philosophers, the mere guessers, have brought us to, they retort. The men of the Middle Ages argued that God made the world for his own glory, and left out the happiness of man. The pious philosophers of the Enlightenment taught that man was a wondrous machine made to exhibit the ingenuity of his Maker. So why have not we the right to say that the world is its own maker, and man's chief end is life, liberty, and the pursuit of happiness? This may be doing much as the medievals did. It may be jumping at conclusions, assuming final ends. But how much better are these ends of ours, continued the revolutionaries, than those ends of theirs. The worship of nature, the religion of humanity, lead to greater good for a greater number than the disparagement of nature and the condemnation of the large part of humanity to present suffering and future punishment.

The answer of the materialists is clearly little but an answer back, except that while the medievalists were pessimistic, they themselves were optimistic. Thomas Paine summed up this hopeful point of view in a series of questions: If objects for gratitude and admiration are our desire, do they not present themselves every hour to our eyes? Do we not see a fair creation prepared to receive us the instant we are born—a world furnished to our hands, that costs us nothing? Is it we that light up the sun; that pour down the rain; and fill the earth with abundance? Whether we sleep or wake, the vast machinery of the universe still goes on.

This is no answer to the mystery of matter. It is only taking the side of matter. Yet this had its excuse because disparaging matter as such led to exaggeration. Therefore the men of the Enlightenment put up a strong case against the men of the Dark Ages. They said that the latter did not understand the problem. They called matter dead and dull, inert and stupid, unable to move itself, the very opposite of intelligence. They reasoned that because it was so low in the scale of being, it should be got rid of as so much rubbish. The body, then, becomes a vile body, to be beaten and whipped into proper subjection to the spirit. It is so worthless that it should be despised and neglected. It is so base that it is a sin to adorn it or even to care for it.

This is actually what was taught by the ascetics, who neglected and disparaged matter whether in the form of clothing or food or of the body. Such teaching was easy to overthrow. It was so extreme that it furnished the very answers to its opponents. Such answers were that it was unnatural that man should crucify his flesh, for man was put on this earth to enjoy himself. It was also untrue to describe matter as dead, passive, and incapable of moving itself. All up and down the scale of being things are alive and stirring. The earth rotates, the planets and their satellites move. So does the world of the infinitely small—the world of molecules, of seeds, of sperms. But people who did not dare to look through a telescope and were afraid of a microscope were poor judges of the capacities of matter. They were the blind leading the blind.

The advancement of science furnished the materialists with their weapons against what they called obscurantism. Yet these very weapons could, in part, be turned against themselves. The materialists fought against a common enemy, yet they also fought with one another. This civil war of the scientists is a curious affair. They were generally called materialists yet all were not. Some of the friends of Holbach, for example, did not believe that man was a mere machine, or that *The System of Nature* explained all the workings of great nature. What then was needed was a real *Interpretation of Nature* as furnished by Diderot in the work with that title.

§ 40. *The Interpretation of Nature*

Diderot is best known as the editor of the great French *Encyclopedia*—the first modern attempt to make a department store of knowledge where customers could find whatever they wanted. Diderot as a naturalist was put among the materialists, but he was only half a materialist. He was a skeptic as to religion; he was also a skeptic as to the so-called science of those who considered man a machine and nature a machine. "Listen, philosopher," he said, "I see the aggregate well enough, the web of small beings each one capable of feeling, but a living being, a whole, a system, a self with a consciousness of his own unity, that I do not see; no, that I do not see!"

Now what did Diderot mean by these remarkable words? It was that matter to which is merely added motion does not make mind in the way that two and two make four. How can mere addition or mere chance in the arrangement of particles create awareness in those particles? A pack of cards however shuffled, however dealt out, does not make a game. The game is in the mind of the player. So with the particles of matter, with atoms, with corpuscles, with whatever you want to call the parts. Move these tiny chessmen about at will, the bishop and the knight, the king and the queen, but they have no feeling of their own.

The materialists, therefore, with their bits of matter [illegible] mind,

are as great dreamers as those who called on the gods to move matter, who put dryads in trees, and the voice of Echo in the rocks. There is a mythology in modern materialism just as there was among those who thought that the oak tree could speak or the statue make a gesture of warning.

So there is something missing here. Let Condillac animate his statue by giving it the lowest of senses, that of smell. Let La Mettrie give general sensibility to his man-machine, does that make either the statue or the machine think? Does it make them know what they are doing? In short, have they awareness, are they conscious of the whole?

"That I do not see; no, that I do not see," responded Diderot the skeptic. So, he argues, we must start deeper down. We must give consciousness to matter at the start, in a word, we must animate the very atom. Suppose that there is a scale of being, a staircase of creatures, then the difference between the lower and higher grades is the difference not of kind but of degree. Not only are all things alive but all things are to some extent aware of being alive. Mind sleeps in the vegetable, dreams in the animal, and wakes in man.

But mind must be sought for even further down, in the mineral kingdom. So Diderot suggests that from all eternity there may have existed elements which had both the capacity of life and the capacity of consciousness. They were alive and, in some dim way, they knew they were alive. Nature is here like a great room with a candle in the center. There in the bright flame the light is concentrated, but there is no nook or corner totally in the dark.

Such a view makes nature self-sufficient. It has life in itself and light in itself. Yet these are not merely mechanical, got by adding one dull particle to another. In matter there is an original spark of life and mind. As new and better conditions arise these possibilities develop. To be actual there must have been something potential—something that had the possibility of coming forth as occasion arose.

This, of course, sounds much like the statement of the regular materialists. But there was more to it than that. The ancients had spoken of the elements as if they attracted and repelled each other, as if they loved and hated. The moderns, like some of Diderot's friends, spoke of sensitive atoms and imagined that by putting these together in various ways awareness or consciousness would arise. "So," replies the critic of blank materialism, "I see the aggregate, the web of small beings; but a self with the consciousness of its own unity, that I do not see."

Diderot had his doubts. He derived these partly through the naturalists and partly through another philosopher. The naturalists were the men who used the microscope and studied minute organisms, such as the tiny creatures in a drop of water. The other philosopher was Leibnitz, who also knew what the microscope had discovered in the waters of a Dutch canal and built up a system based on what he had seen with his own eyes.

The acute German, writing more than a century before Diderot, also had his doubts. He felt that the moderns had carried reform too far in reducing everything to the machine. Naturally no one would be foolish enough to deny mechanical connections between material bodies, but that is not the whole explanation. Every substance works, but why does it work? It is because there is within it an "internal perfecting principle," a psychic something which pushes it on! Nonsense, replied the materialists. There are sensitive atoms and that is enough. But why do they develop as they do? queried Leibnitz; why do they arrange themselves in a scale of being—mineral, vegetable, animal, human—in an orderly series where there are really no gaps? How is it that we are finding out that there are no broken rungs in the ladder of life?

Thus the microscope of his friend Leuwenhoek had disclosed to Leibnitz those microörganisms we now call bacteria. Are these plants or animals? asked Leibnitz. No, they are intermediate forms. Some of these minute creatures look like plants, but are free-swimming like animals. Others are evidently animals, but act like plants; they are parasites stuck in one place.

Here is a clear case of science changing a system. Just as the telescope had led to the discovery of new bodies in the universe of the great, so the microscope unfolded unsuspected bodies in the universe of the small. A drop of water from the Dutch canal was now seen to swarm with life. The new instrument of precision had discovered the seeds, the sperms, the germs of things. All this led Leibnitz to build up his system of what he called monads. As material, monads are machines; as spiritual, they are minds. As a whole, with the two aspects combined, monads are living machines or organisms.

Now this was the doctrine that greatly influenced

Diderot. It made him doubt that man is a mere machine. It forced him to imagine that matter was made up of more than masses and forces. In short, he was obliged to reach the conclusion that matter was itself sensitive.

Now this doubt and this thought had great influence on the future. It raised the question whether the world, by and large, is run by mechanical forces or spiritual; it brought to an issue the fight between those who are called mechanists and those who are called animists. This fight is a kind of football game where first one side and then another is pushed over the line. Notice what has taken place and what is to take place. Copernicus, Galileo, and Newton had used mechanics to explain the workings of the great world. Leibnitz comes in and declares that mechanics will not explain the world of the little, the realm of microörganisms. So even the French materialists are forced to modify their claims, to grant that mechanical combinations will not explain everything. But the struggle does not end here. The rival forces sway to and fro. The problem is tackled by Kant, the great German critic. Nature, he declares, is a queen ruling over two realms, that of the inorganic or lifeless, where mechanism explains all, and that of the organic or living, where purpose is to be seen, purpose because of some indwelling spiritual principle. A house may be built mechanically, but it is meant to be lived in by an intelligent being.

This division of labor between the material forces and the spiritual was accepted for a comparatively long time. Kant was so wise and so fair in his judgment that he was looked upon as a perfect umpire. Yet he made one judgment that really gave the game to the mechanists. Here is the famous utterance:

> It is quite certain that we cannot become sufficiently acquainted with organized creatures and their hidden potentialities by aid of purely mechanical natural principles, much less can we explain them; and this is so certain, that we may boldly assert that it is absurd for man even to conceive such an idea, or to hope that a Newton may one day arise even to make the production of a blade of grass comprehensible, according to natural laws ordained by no intention; such an insight we must absolutely deny to man.

This statement at the time when it was uttered seemed to make the game a draw. It gave so much to the mechanists and an equal amount to the anti-mechanists. But a Newton did arise to explain the production of living organisms by natural laws. This was Charles Darwin, whose *Origin of Species* brought forward an overwhelming mass of evidence in favor of natural selection through the struggle for existence, and all leading to the survival of the fittest.

These phrases for the nineteenth century were what "life, liberty, and the pursuit of happiness" were to the eighteenth. But now in the twentieth century the game has been renewed. Is natural selection everything, is all to be explained on mechanical laws, is the world at large a vast machine, unfeeling, relentless, grinding out new species and all without a general plan or purpose? There are thinkers to-day who try to solve the doubts of Diderot, who seek "a living being, a whole, a system, a self with a consciousness of its own unity." Such are Henri Bergson with his *Creative Evolution,* Sir Arthur

Thomson with his *System of Animate Nature,* and C. Lloyd-Morgan with his *Emergent Evolution.* These are the latest contestants put up on the score board of evolution. But we must now go back to the very beginnings of the game and strive to follow the zig-zag course of the players.

BOOK V

The Age of Evolution

§ 41. *The Early Greek Anticipators*

The first half of the game of evolution was from the Greeks to Darwin. The last half—if ever there is a last—is from Darwin to the present day. Aristotle has been called the father of the doctrine of evolution. Naturally he had some ancestors. Before the greatest of the Greek thinkers there were several clever guesses made as to the origin of the world and living creatures. There was an evolution of the idea of evolution itself, a struggle for existence among the various theories as to the birth and development of things.

Here we have to go back as far as Anaximander, pupil of Thales, the first physicist. Like his master, he believed that the earliest condition of the earth was fluid. As the earth dried up, living creatures came forth upon the shores, and the first of these were men, or rather mermen. They came from the sea where they had lived like fish, reached the shores and shed their scales as crabs shed their shells. This notion is a mixture of mythology and observation. The Babylonians had their fish-men, and any one walking along the shore could see the discarded husks of shellfish. Combine the two, and you have the first crude idea of an emergence of one form from another, due to a change of habitat from one sphere to another.

Anaximander's pupil, Anaximenes, improved the theory of his master. He discarded the myths and put the start of living creatures in a mixture of water and earth. He believed that from an original slime, warmed by the sun's heat, all living creatures—vegetable, animal, human—came forth, just as people not long ago believed that eels were generated directly from mud.

These ideas are suggestive. They show the Greeks in biology, as in astronomy, thinking themselves away from the supernatural and towards the natural. Further advance was made when speculation moved from eastern to western Greece. Empedocles of Sicily—the same who perished in the crater of Mt. Ætna—had brought forward the doctrine of strife among the dead elements. This he now extends to living elements. Thus he makes animals not as a whole, but in parts strangely joined together: "heads without necks, arms without shoulders, eyes without their sockets." This was probably meant to explain mythological monsters, such as the Egyptian deities, with heads of hawk and jackal, or the minotaur of Crete, the cruel bull with the head of a man to whom the tribute of youth was sacrificed. But the story of Theseus' fight with this monster and of the labyrinth of Crete is to science a mere "Tanglewood Tale." However, the notion of partial creatures, of monstrous beings, had in it the germ of later truth. Empedocles pointed out that animals with the heads of men, such as a centaur, were unnatural creatures who could not persist. It was only when the proper members were assembled in their proper order that survival of the fittest could take place.

These were but gleams in the darkness. Yet as the author of the book *From the Greeks to Darwin* suggests, these happy conjectures of Empedocles furnished four sparks of truth—first, that the development of life was a gradual process; second, that plants were evolved before animals; third, that imperfect forms were gradually replaced (not succeeded) by perfect forms; fourth, that the natural cause of the production of perfect forms was the extinction of the imperfect.

The early Greek thinkers threw out veritable sparks of truth. These were real flashes of genius because they lit up one dark side of the road of evolution. That side was the mechanistic, where the origin of things is to be explained by chance and not by purpose; by accident and not design. While these earlier views were in part preserved, the later Greek thinkers of the idealistic type refused to accept them in their entirety. Chance and accident were repugnant to those who believed that the entire world was a cosmos, an orderly and beautiful whole brought into being by divine design.

Such a believer was Aristotle, who fought the doctrine of chance, especially in its more refined form of atomism. How absurd it is to argue, he said, that the mere mixture of an infinitude of tiny particles can ever form this fair world that shines about us, this fixed arrangement of natural kingdoms—mineral, vegetable, animal, human. As well expect that from countless alphabets, mixed by chance, old Homer's story of Ulysses could come forth.

No, it is not chance, accident, a happy throw of nature's dice that explains creatures from polyps to poets, it is divine design, an infinite purpose which has put a perfecting principle into all things, such as a crystal in a rock, an oak in an acorn.

§ 42. *Aristotle, Father of Biology*

Aristotle, as we have seen again and again, was wrong in his astronomy. It is different with his biology, or the science of living creatures. In his famous works on *The History of Animals* and *The Parts of Animals* he anticipated much that is modern. He was able to do this because he had unusual advantages. As tutor to Alexander the Great he obtained specimens of rare creatures from the strange lands traversed by the conqueror. As a citizen of Athens, with its seaport, he had at hand a practical marine biological laboratory. Lastly, as a member of a family of physicians, he had early chances to gain a knowledge of anatomy.

These things helped him so much in his studies that he achieved, for a man of his day, tremendous things. He listed five hundred species of mammals, birds, and fishes and made many acute observations on polyps, sponges, and cuttlefish. He put forward a scheme of an ascending scale of beings from polyps to man—"the wisest and most thoughtful of animals." He gave a hint of protoplasm, saying, "It is necessary that germs should have been first produced and not immediately animals; and that soft mass which first subsisted, is a germ." Most important, he anticipated the doctrine of epigenesis in embryonic form. This means that man before birth goes through various successive stages: "At first it seems as if the embryo reveals the life of a plant, then an animal, then a vertebrate, then a mammal, and finally a particular kind of mammal."

Over against these achievements many mistakes must be put. For example, Aristotle made the brain, not the organ of thought, but a kind of refrigerator for the blood: "Keep your head cool" might be said to be his piece of advice. He also exaggerated the principle of economy in nature. It is not untrue to say that what nature spares from the teeth of a cow goes to the making of its horns; it is too much to say that the reason a bear has a short tail is because there is not enough fur to provide a longer one. Finally, Aristotle fostered the myth of what is called abiogenesis, that is, that life may come from the lifeless; for instance, frogs, snakes, and eels from mud. This was later called spontaneous generation and was not disproved until the nineteenth century and the time of Pasteur. Water, for example, as one of the natural elements, does not contain germ life provided it has been Pasteurized, or almost boiled. If germs have thus been killed, that proves that all life must come from previous life.

This leaves one great problem unanswered, the origin of life itself. This has been called the riddle of the universe, and various solutions have been put forward to solve it. The older atomists had their sensitive atoms, and modern monists, or single-substance people, have had recourse to chemistry. They say that living and lifeless bodies are composed of similar stuff, and that nature, ages ago in her prehistoric chemical laboratory, when heat was greater and other conditions more favorable, compounded life chiefly out of the four chemical elements carbon, hydrogen, oxygen, and nitrogen.

This is a speculation which cannot be disproved. As Aristotle lived long before the age of creative chemistry, all he could do was to take life for granted in the descriptive part of his work. In the ascending scale of being it is plants that first have life, "for that which nourishes itself, grows, and decays, we call living." This is plain description, yet Aristotle cannot forego an explanation. Instead of making matter itself develop life, he puts potential life into matter. This potency he calls form, a perfecting principle injected into matter by the Creator. This form, once started in its development, grows more and more complex. It adds to its own functions as it moves higher up in the ladder of existence. In plants it has the powers of nourishment and reproduction, but no feeling or sensibility; in animals it has these powers plus sensibility. Seeking for food, the animal is not fixed to one spot like plants, but moves about and thus increases the power of locomotion. Lastly, the form, or internal perfecting principle, comes out most fully in man, for man has all the previous powers and in addition the power of reason.

This is the scheme of evolution propounded in the fourth century before Christ. We can at once see how superior it was to the mythological views of the Near East. The Babylonians and the Hebrews had taught a kind of oriental despot view. Just as a king can create offhand various grades of nobles and court officials, so the celestial King of Kings can create by his mere command the various heavenly bodies and earthly creatures, it may be in the space of six days. In the history of evolution this is called the doctrine of special creation. With it goes the doctrine of intervention.

The king can do no wrong, but if his subjects do, woe to them! They can be degraded and destroyed and other creatures put in their place. So with the Creator King; he can punish wicked man by a deluge and save a remnant of man and beasts only by a miracle, as in the story of Noah's Ark.

To the Greek mind, this was unnatural. The Greeks evidently did not take these notions seriously, for they quickly got rid of their early creation myths, such as that in which Deucalion and Pyrrha created men and women by throwing stones back over their shoulders. They also did not care for despotic acts and the arbitrary ways of oriental rulers. They feared the Great King of Persia, and fought against him and his system.

So their philosophy was like their politics. It was orderly and rational. As Aristotle put it: "Nature can only rise by degrees from lower to higher types." This means that it is only very slowly that you can overcome matter and put form into the chaos of the elements.

Nature, then, is like a laborious artist. She works as does the sculptor, who with many slight blows hews the statue out of the rough block of marble. All this labor and delay is due to the fact that crude matter offers resistance to the emergence of form.

§ 43. *Aristotle and Darwin*

In his doctrine of form, Aristotle brings in a difficult problem which has made him seem an evolutionist in one sense and not in another. Is the form already hidden in the block of marble? Only figuratively so. It is the mind of the master sculptor which carves the material to suit his purpose. Still we know of some masterpieces which have been left unfinished because of a defect in the material, such as a hidden vein of discoloration. This, according to Aristotle, would explain why nature does not always attain her end. Because of these unexpected obstacles Aristotle is forced to change his figure of speech. Human art, working over dead matter, is comparatively a small thing. A greater is the world of living nature—plastic matter already containing in itself the principle of growth, in a word, that "soft mass which first existed as the germ."

Now in all organic creatures, even in the lowest animals, we find something admirable, full of purpose, beautiful and divine, as Aristotle expresses it. This something is the perfecting principle put in by the prime mover of original matter and left to develop towards a final end—"fitness, adaptation, or purpose, the good of each and all." All this at first glance sounds strangely like Darwinism. In his great book, *The Origin of Species,* Darwin said: "From a few forms or one, through the laws of growth, with reproduction, inheritance, variability, struggle for life, natural selection, endless forms most beautiful and most wonderful have been and are being evolved."

Aristotle has been rightly called a forerunner of Darwin. But the evolution of the idea of evolution is more like a relay race than a marathon run. The Greek thinker came only part way for he suffered the handicap of a preconceived idea, that of divine design. He passed over the first stages in the race and, like Darwin, believed in reproduction, inheritance, variability, but he stopped at natural selection and a struggle for existence. In its place he put supernatural selection and the preëxistence of forms. In general this meant design and not chance, a world of things that had to be because they were foreordained, not a world of things as they are, because they happened to be.

Darwin, it is true, explained that he used the word chance as if it meant the cause of variation, but that was only because it served to acknowledge plainly our ignorance of the cause of each particular variation. Such caution was not in the nature of Aristotle. He often leaped to conclusions, and in the minds of many failed to reach the goal just because of that. Of course he had sense enough to see that there are chances and mischances in the world. By chance, he says, I dig in the field and find treasure; by chance cold weather sometimes comes in the dog days. But such chances, he adds, are only haphazard; they lead to nothing. In a word, there is no reason in them, so they are quite useless and can be disregarded.

But Darwin, as we shall see, made great use of chance. He points out that by taking advantage of chance variations our best stocks, animal and vegetable, have been evolved. By watching for chance variations, breeders have evolved the race horse; fanciers the carrier pigeon; and horticulturists improved strains of grains, fruits and flowers. They are constantly on the lookout for what they call sporting varieties, as means for advancement and progress.

We might almost say that these men are like professional gamblers who take their chances and stake much on their "system." Now Aristotle is quite out of sympathy with this way of looking at the world. He ridicules those who claim that animals came into being by chance. He scoffs at Empedocles and his negative cases of hybrids which perished because they were unfit. Creatures with the bodies of bulls and human heads have no significance whatever. The minotaur was a monster and that is all there is to it. So in place of a world of chance he puts a world of design. The order of nature demands a reason, a plan, a purpose, back of all. Chance is blind; design sees. If there is order in nature, there must be an orderer, an all-seeing being who puts plan and purpose into all things.

This sounds perfectly familiar and perfectly plausible. It has been made so by an historical accident, by the fact that the Church happened to take Aristotle for its authority in biology just as it did in astronomy. But the former view may be as false as the latter. Just as Copernicus overthrew the system of the earth-centered universe, which did not work, for a sun-centered universe which did, so with Darwin. He has been called the Copernicus of the world of living creatures because he gave a natural explanation in place of a supernatural.

The old astronomers, followers of Ptolemy, as we recall, had recourse to spirits and angels rolling their spheres along in the celestial regions. It is a beautiful fancy which lent itself to art. But the new astronomers had recourse to matter and motion and explained the action of the celestial bodies without the help of heavenly beings.

The same problem arises in biology. One writer has spoken of the enormous hindrance presented by the dogma of design throughout thousands of years to the progress of humanity and science. We must therefore take up the other side and see what can be said for the opposite view, that of chance as the principle at the bottom of organic evolution.

§ 44. *Chance versus Design*

Those who follow Aristotle say that design is at the bottom of evolution, and that only a divine plan explains the gradual and orderly unfolding of the processes of nature. Prove it, say the advocates of chance. That which looks like design is only a kind of habit into which nature has fallen. We observe that nature acts thus and so, but those actions are not necessary, according to a plan thought out beforehand. Take the case of people. Their habits have only grown up by accident. When they become engrained and turned into regular actions would you call them part of a deliberate design? Watch your neighbors from your window. The man at your right bursts out of his door, rushes down the steps, cuts corners, and disappears in a hurry. The man at your left carefully closes the door, stops to consider the weather, walks deliberately to the proper street crossing. Now suppose that there were two dogs belonging to these two men. Each would have to suit his actions to the conduct of his master, and each might think that the other dog's master had no rhyme or reason in his actions, be they fast or be they slow. Now which of these ways of action is designed? Neither. Each is due to chance, the accident of birth, which made one nervous and excitable and the other slow and deliberate.

Thus looking out upon nature the advocate of chance would simply say that accident accounts for things as they are. Thus it rains because it has to rain; it is dry because it has to be dry. There is no rhyme or reason in the weather. Even your great Aristotle's argument could be turned against him here. He says: "Some may question what hinders nature from operating for some purpose rather than necessity; for example, the rain falls for the benefit of the corn. Similarly, if someone's corn is destroyed by rain, it does not rain for this purpose, but as an accidental circumstance."

This gives the case away, says the other side. The weather acts as it does because it has fallen into that habit. We call these habits laws, but there is no especial reason in these laws. It is a "just so" world, and we might as well get used to it and try to accommodate our conduct to its capricious ways. This is like one of the dogs mentioned: if he belonged to the man in a hurry he would have to be on the jump; if he belonged to the leisurely master he could take his time.

This world then is a chance world and a world of chances. It therefore behooves us to be on the watch. The wheel of fortune rolls now this way and now that. Keep your eyes open, for you never can tell what is going to occur. Fortune is a fickle jade, so embrace your opportunities as they come. "Take the goods the gods provide thee." If you are not quick enough, the chance may never come again. All this sounds familiar. It is the practical side of that ancient philosophy of atomism against which Aristotle fought so hard. It is the old system which really had in it the principles of the struggle for existence and the survival of the fittest. Fortune distributes her lots impartially and it is only the clever and alert that gain the prizes in the lottery of life.

This was a horrid doctrine to the advocates of design. Thus Aristotle was all for an internal perfecting tendency in nature, which made man the final goal of all its development. He declared that plants are evidently for the sake of animals, and animals for the sake of man; thus nature, which does nothing in vain, has done all things for the sake of man.

This is a vain dream, retort the believers in chance. Design is an afterthought. It happens that man has come out on top; there is no evidence that other creatures, such as insects, might not have done the same, or that some supermen, some visitors from Mars, some creatures as yet unknown may not be the coming race. Believers in design simply flatter themselves that things as they exist are perfect. They take things for granted in the broad world just as Aristotle did in his picture of the perfect household. Here slaves were considered part of the household furniture, the husband the head of the house, the wife and children subject to the husband, in short, man the master of all. The system that happens to be is thus taken for the only system and the best system. It is all very well for those on top, but if they think that it is all arranged for their benefit, they are mistaken. Slaves may be more clever than the master, as in the case of Spartacus and his band of gladiators; wives more masterful than husbands, as in the case of Xantippe and Socrates.

History repudiates this notion of design, continue the advocates of chance. History is a chapter of accidents; now the prince wears the purple, and now the pauper; now one nation is on top, and now another. The world is a confused wilderness, not a formal garden. The universe is a wide open universe, not a neatly arranged scheme where man is the end of nature and monarch of all he surveys.

Now this last view in turn is not liked by many, or even by the majority of men. Instead of a world of chance and chaos, they prefer a world of providential design. This preference gave strength to the followers of Aristotle and was a source of weakness to those who followed atomism, where nature seemed merely to be playing a game of hazard and quite indifferent to the pawns and pieces in the game.

Aristotle had faced this question and put up a strong fight against what he called fortuity in nature. Suppose, he says, that at the time of the Trojan War any one had observed the advantageous disposition of the Greek army and the subordination of its movements which led to victory. He would have had the right to suppose that there was a guiding purpose behind it all. So with nature. It has its disposition and arrangement. This is apparently inherent, but is really due to a general in the background. Nature, then, according to Aristotle, has a definite plan of campaign and the order of the day is only that which is gradually unfolded from a plan thought out beforehand.

There is no such grand strategy, respond the critics of this view. Many things happen in the growth of animals simply because it happened in their generation. For example, a spine composed of many vertebrae is not produced for some purpose, but from chance or accident. To this special instance Empedocles adds the general statement: "When all things happen as if they were made for some purpose, being aptly united by chance, these were preserved, but such as were not aptly made, these were lost and still perish." Darwin [illegible].

Now for "aptly" in the above passage, put "adaptively" and Aristotle's rival is the real anticipator of Darwin's principle of adaptation through chance variation. In one stroke, then, he got rid of what is called the doctrine of final causes or "ends" of creation. This doctrine could mean one of two things, according as the final cause is put in the future or in the past. Aristotle favored the latter. His prime mover gave the push from behind which sent things eternally forward. Many moderns favor the former. They put the final cause in the future. It is a goal ahead, which like a magnet draws objects towards it. Such is Tennyson's "far-off divine event to which the whole creation moves."

This is all very well, concludes the other side in rebuttal, but it is assuming too much. This kind of manifest destiny is not so manifest to us. All we see are the changes that take place day by day. Secondary causes are good enough for us. Yet even these secondary causes were not made with any purpose. Birds were not given wings in order that they might fly, but they flew because they happened to grow wings. When Aristotle declares that man has been endowed with hands in order to reach superior intelligence, we say that he chanced to develop hands and thus reached his superior intelligence. Therefore chance is everything, and final ends are only afterthoughts.

The [illegible]?

§ 45. *Lucretius, the Roman Poet of Nature*

The people who first talked against Aristotle and his arguments for design were the Epicureans, known as the philosophers of the life of pleasure. In reality they were atomists, and their reasoning was as follows: Assume an infinite number of atoms, infinite time, and infinite space. Then, out of the countless combinations of these smallest particles of matter which have been tried through the boundless ages of the past, those only survive which were found to be suited to their environment or surroundings. Thus chance and not design is the rule of nature. The eye, for example, is not made to see with, but being made by the fortuitous concourse of atoms it was found on trial to have the property of seeing.

This doctrine was taken up by Lucretius, a Roman writer of the first century. In his remarkable poem *On the Nature of Things* we find many thoughts that remind us of Darwin's *Origin of Species*. But where Darwin was cautious in the use of the principle of chance, using it, as he explained, simply as a cloak for our ignorance, Lucretius boldly follows Epicurus. He confesses that it is hard to make clear in Latin verse the dark discoveries of the Greeks, but nature's first principle may be stated thus: "Verily not by design do the first beginnings of things station themselves each in his right place, occupied by keen-sighted intelligence . . .

but because after trying motions and unions of every kind, at length they fall into arrangements, such as those out of which this our sum of things has been formed."

From all this it follows that there is no divine design in the universe. Yet, even without this theory, observation shows that this is so, declares the poet.

> If I did not know what the first beginnings of things are, yet I would venture to affirm that the nature of things has not been made for us by divine power, so great are the defects with which it is encumbered. Of this vast earth a portion of mountains and forests wild beasts have occupied. Next of nearly two-thirds burning heat and the constant fall of frost rob mortals. What is left for tilling, even that nature by its power would overrun with thorns unless the force of man made head against it. And even then sometimes when things earned with great toil now put forth their leaves over the earth and are all in blossom, either the sun burns them up with excessive heats or sudden showers and cold frosts cut them off. And the blasts of the wind waste them by a furious hurricane. Again why does nature give food and increase to the frightful race of wild beasts, dangerous to mankind both by sea and land? Why do the seasons of the year bring diseases in their train, why stalks abroad untimely death?

This is a dark picture drawn by the practical Roman. But it appears more true than that of Aristotle, the advocate of the principle of design—"fitness, adaptation, or purpose, the good of each and all." As this disposes of the ancient argument for final causes it also is opposed to the later philosophy of optimism—of a creator who out of all possible worlds chooses the best possible world which is this one on which we mortals dwell. So Lucretius was ever a stumblingblock to those who argued for divine design. If Providence controls every detail, the design would be better than it is.

This picture of the preponderance of evil things in the world and of man's dire struggle for existence gives point to the poet's first principle—"for verily not by design do the first beginnings of things station themselves each in its right place by keen-sighted intelligence." But more is to follow in the way of anticipating certain modern arguments against a too rosy outlook on nature.

Thus the struggle for existence is portrayed. And with this goes not only the survival of the fittest, but what is so often forgotten, the non-survival, or destruction, of the unfit. Hence the poet proceeds:

> Many races of living things must then have died out and been unable to beget and continue their breed. For in the case of all things which you see breathing the breath of life, either craft or courage or else speed has from the beginning of its existence protected and preserved each particular race . . . but those for whom nature had granted none of those qualities, those, you are to know, would lie exposed as a prey and booty to others, hampered all in their own death-bringing shackles, until nature brought that kind to utter destruction.

[illegible], [illegible], [illegible] man ?

This sounds highly modern. So do the further descriptions of primitive man and of man as he emerged from the Stone Age and passed gradually through the Age of Copper and the Age of Iron:

> Arms of old were hands, nails and teeth and stones and boughs broken off from the forests, and flame and fire, as soon

> as they had become known. Afterwards the force of iron and copper was discovered; and the use of copper was known before that of iron, as its nature is easier to work and it is found in greater quantity. . . . Then by slow steps the sword of iron gained ground and the make of the copper sickle became a thing of the past; and with iron they began to plough through the earth's soil, and the struggles of wavering war were rendered equal. . . . Next the Carthaginians taught the elephants with towered body, hideous of aspect, with snake-like hand, to endure the wounds of war and to disorder the mighty ranks of Mars. Thus did discord beget one thing after another, to affright nations of men under arms, and every day made some addition to the terrors of war.

So much for Lucretius. He portrays the system of nature from atoms to cavemen, and from cavemen to the fighters of classic times. He was not liked because he ran counter to certain high and mighty ideals. When it came to the Christian Fathers they called him a pagan and left it at that. When later scholars from time to time sought to employ his arguments, they did so at their peril. Etienne Dolet tried to revive the system of the Latin poet and was burned at the stake in the Latin Quarter of Paris. Gassendi, the opponent of Descartes on the idealistic side, essayed the same thing, and was practically forced to change his views to suit the authorities. Thus when the great revolution in astronomy was under way we find Gassendi favoring Tycho and not Copernicus. This he confesses is because there is a decree of the Church which bids us believe that the world is at rest and not in motion. The same constraint hampered him as an evolutionist. He followed the ancient atomists but he did not follow them the whole way. His system was a real atomism, but to it was added a kind of animism or belief in a world soul. It seems as if after building a structure of plain bricks, he was forced to add to it a medieval spire. This addition appeared to him at times out of place. He had an uneasy feeling that he had mixed two orders of architecture—the natural and the supernatural. And yet at other times Gassendi is not satisfied with mere mechanism. He considers the human body to be so fearfully and wonderfully made that he is led to write these lines of reflection:

> The construction of a palace appears to us marvelous with its endless processes: the wood has to be brought from the forest, the stone from the quarry, and all the parts have to be shaped and fitted together; but in this case we see the agents—architect, masons, and woodcutters, and if we still find cause of wonder in this, how much more should we marvel at the construction of a living body where all the agents are unseen and the structure has to be maintained by incessant repair! We must not think that we can exhaust nature; there is something that does not fall in the range of human powers, and while we cannot completely explain nature, we must so far bow before it as to acknowledge that the whole is more than the parts.

§ 46. *Chance and Design*

Gassendi has left us somewhat in doubt. He starts as a materialist and ends as only half a materialist. His building materials are atoms, but for the life of him he cannot see how mere atoms can build themselves up into a human body, much less into the great world body.

This kind of doubt is just the thing needed in the evolution of the idea of evolution. Aristotle had tried the scheme of all design and practically no chance. Lucretius had tried the converse scheme of all chance and practically no design. Is a compromise possible? Gassendi thinks so. He declares that we must not admire the temple and ignore the architect. As some creative power, both wise and intelligent, has to be acknowledged, it makes little difference whether we call it nature or Creator. Yet to grant this alternative between nature and Creator was of course a dangerous doctrine. It was called pantheism, if it allowed nature to take over the attributes of deity and to be considered an independent whole which could run itself, by itself, and for itself.

So Gassendi, like his predecessor Bruno, was looked upon as a kind of rebel, drifting away from the old authority and setting up an independent government. But see how he defended himself. He does not say that it is all chance in the world, for that would lead to a kind of anarchy in creation, and to the production of those monsters and chimeras imagined by Lucretius. On the other hand, he does not say that it is all design in the world, for he asks such a question as this: If rain falls on the crops by design, why does it also fall on the sea and the rocks?

No, it is not all this or all that. It is partly design and partly chance, and nature, which is "capable of choice," has determined that from the innumerable host of the Creator only some survive.

"Nature capable of choice" is a wonderful saying, and it rightly put Gassendi in the line of those who anticipated the doctrine of natural selection. Of these anticipators, these forerunners of Darwin, there are many. A list of over forty has been compiled. Out of this list we need select only enough to make up a complete team, for the game of chance versus design is only begun when Gassendi appears on the field.

There is, as we now know, a long list of candidates for the honor of being anticipators of the doctrine of natural selection. Out of this list we shall take only the most prominent and see what they stand for. Here there are two groups, the speculative evolutionists and the real naturalists. The first indulged in flights of fancy, while the second group, who really counted, were those who depended on hard work. Among the latter were such men as Lamarck and Erasmus Darwin, the grandfather of Darwin himself.

The first group depended more on speculation than on observation. They largely took over the views of the ancient atomists, whose motto was chance. Like Empedocles and Lucretius they relied on matter as the all-sufficient substance. Their point of view was that the universe was purposeless. Early in this list comes the revolutionary Frenchman Diderot. Here is his speculation as to the origin of species:

> Even if Revelation tells us that species left the hands of the Creator as they are now, the philosopher who gives himself up to conjecture comes to the conclusion that life has always had its elements scattered in the mass of inorganic matter; that it finally came about that these elements united; that the embryo formed of this union has passed through an infinitude of organization and development; that it has acquired, in succession, movement, sensation, ideas, thought, reflection, conscience, emotions, signs, gestures, articulation, language, laws, and finally the sciences and arts; that millions of years have elapsed during each of these phases of development, and that there are still new developments to be taken which are as yet unknown to us.

Diderot, the doubter, also had some views as to the survival of the fittest. In one of his imaginary dialogues he goes on to say:

> I may at least ask of you, for example, who told you—you and Leibnitz and Clarke and Newton—that in the first instances of the formation of animals, some were without heads and others without feet? I may mention . . . that all the faulty combinations of matter disappeared, and that those individuals only survived whose mechanism implied no important misadaptation, and who had the power of supporting and perpetuating themselves.

These were fairly good questions and objections, for they raised important problems which others were to solve later. But there was another Frenchman of that revolutionary period who gave such silly answers to similar questions that his views remain only as curiosities. De Maillet has before him the problem of transformism—that is, of the change of one species into another. Here is his solution. Birds come from flying fishes, snakes from fishes "rampant," or raised up, lions from sea lions, and man from the merman, or husband of the mermaid!

The opponent of modern evolutionism may claim that this is no more silly than the line of descent now believed in, where fish, reptile, bird, and mammal succeed one another in the geological ages. But the modern evolutionist has this evidence in his favor. He has actual fossil records of actual "missing links" between fish and reptile, between reptile and bird. Such are creatures like the icthyosaurus, or giant "fish-lizard," and the archæopteryx, the bird with traces of the reptile. He can also point to embryology, where the unborn young of the higher mammals have in succession traces of the previous stages of reptile and bird.

But De Maillet made his fish-birds and fish-snakes come suddenly into being. Within a single lifetime a flying fish could change into a bird, because by chance, being carried ashore, the air would change their front fins into wings, scales would become feathers, and the ventral fins become legs. Lastly, "the neck and the beak became elongated, and the fish discovered itself a bird."

§ 47. *Forerunners of Darwin*

De Maillet perhaps realized that his views were too preposterous to pass, because he put them forward in an anonymous book called the *Telliamed*. This title is an anagram formed by spelling the author's name backward. However, another Frenchman of that time brought forward a theory of transformism which had more sense to it. Maupertuis brings in chance, but he also allows plenty of time for change of species. Instead of the change occurring in a single lifetime, it takes generations to bring it about. He supposes the embryo made up of elementary particles, drawn from the corresponding structure in the parents. If some of the particles happen to be missing, an imperfect being is formed. If, on the other hand, the elementary particles do not always retain the order which they present in the parents, they may fortuitously produce differences, which, multiplying and accumulating, have resulted in the infinite variety of species which we see at the present time.

Such were the men who favored chance as the principle at work in the world of living creatures. Opposed to them were other so-called evolutionists who took the opposite side. These were the thinkers who, consciously or not, were the followers of Aristotle. Their motto was design. Their point of view was that the universe was purposive. They relied on some internal perfecting principle as the real explanation. The foremost of these was Charles Bonnet. He took the word e-volution in its literal sense of unrolling. Just as a magician can pull forth a seemingly endless ribbon, first red, then white, then blue, so nature unrolls a continuous series of forms, mineral, vegetable, animal. This is really Leibnitz's old chain of being. But with the Frenchman the chain is apparently an endless chain; it goes from atoms to archangels, from chemicals to cherubim.

This curious theory has been called the box theory of evolution. Working it backward it is like a nest of boxes, a series of embryos, each containing a smaller embryo. Open one, and there is a smaller one inside. Open that, and there is another still smaller. Keep this up, and you come to a box so small that it cannot be seen. What then? Bonnet replies that you may have to imagine something invisible at the bottom of the scale of being, for when you come to think of it, evolution is nothing but "the expansion of the invisible into the visible."

Erasmus Darwin, the grandfather of Charles Darwin, made great fun of this theory. He put the absurdity of it in this way:

> Many ingenious philosophers have found so great difficulty in conceiving the manner of reproduction in animals, that they have supposed all the numerous progeny to have existed in miniature in the animal originally created. This idea, besides its being unsupported by any analogy we are acquainted with, ascribes a greater continuity to organized matter than we can readily admit . . . these embryons . . . must possess a greater degree of minuteness than that which was ascribed to the devils who tempted St. Anthony, of whom twenty thousand were said to have been able to dance a

saraband on the point of a needle without the least incommoding each other.

By using the word evolution in the sense of unfolding Bonnet was responsible for a great deal of confusion in people's minds. His doctrine also offered the greatest possible hindrance to the acceptance of evolution, as known among scientists. The notion of miniature models is what is known as preformationism. This means that there is no more to be got out of the world than was originally put into it. The original world-plan was like a photographic roll which had been exposed but not developed. The pictures were already there potentially, so pour on the "developer" of time and circumstance and they will come out. Now this is the very opposite of Darwinism or transformism. This means that given original living matter, vague and unformed, then time and circumstance and the forces of nature will change it into the countless creatures that exist on this globe. This first stuff of protoplasm, as the name implies, is plastic. It can be molded into almost anything, but it can never be known beforehand precisely what it will be molded into. There is no literal development of a divine design. There is no belief that a god foreordains whatsoever comes to pass. All that shall be was not given ages ago. Instead of a Book of Genesis, where every animal is created "after its kind," and all very good, the modern evolutionist offers a book of epigenesis. This means that creatures were not originally created as fixed species, but come into being by chance, some to survive, and others to perish, because unfit to survive in the struggle for existence, as shown in the stages of the embryo.

Bonnet and his school were too near the Age of Mechanics not to be affected by it. Theirs was really a factory system where the molds, being once made, could not be changed unless by arbitrary action. Their theory of descent was that of quantity production. Given an original model, the rest of that species had to be like that model.

However, there was one way out of this. When geology came in to show that there had once existed prehistoric creatures of which no living examples remain, they said that this could be explained. The Creator had become dissatisfied with his creatures, had found, for instance, that certain primitive monsters were too slow and clumsy to succeed. He therefore brought about a cataclysm—a great flood, an earthquake, a sinking of the land, which wiped the old models out of existence. Having done this he was at libery to make new patterns, to start in quantity production again on new models.

This was an ingenious explanation. It puzzled some of the early geologists, but as the "testimony of the rocks" came in, it was found that there had been no such enormous cataclysms—no universal deluge to drown a wicked race, no world-wide earthquake to punish the imperfect. Instead of that, the testimony of the rocks made a consistent story. Many leaves might be missing here and there, but in general the chapters of the geological history formed a fairly unbroken serial. Missing links were found. There was not an age of fishes, then of reptiles, then of birds, then of mammals, and all the ages separated by dark gaps of destruction. No, the geological record began to fill up these gaps, began to discover the clues in the plot, until geology came to take the view that the processes of earth building were uniform. This was the rise of the "uniformitarian" school, to which belonged Charles Lyell, whose views had such an influence on Darwin himself.

§ 48. *Evolution and the Naturalists*

Bonnet and his view represented the end of the eighteenth century. His notion of cataclysms was a kind of French Revolution in nature. Creatures that did not succeed were wiped out by the violence of flood, earthquake, and the like, just as a do-nothing king and idle nobility were destroyed by the guillotine. But with a new century a new school arose. Instead of sudden and arbitrary means of getting rid of the imperfect and useless, slow and natural means were called in. Here Buffon, the French naturalist, had this to say: "Species less perfect, more delicate, less active, less armed, have already disappeared, or will disappear. Here the course of nature is always constant, always the same."

This is the negative side. It shows that there are no fixed species, any more than there are fixed social classes, where the king and nobles have divine rights. It was this view that led Darwin to put Buffon first in his *Historical Sketch of the Progress of Opinion on the Origin of Species*, for, as the Englishman explains it, until recently the great majority of naturalists believed that species were immutable productions and had been separately created.

Unfortunately the French naturalist varied so in his views that Darwin could not give him greater credit. Yet Buffon, as we now see him, was touched by the revolutionary spirit. At first he agreed with Linnæus, the famous Swedish botanist, that scientific classification depends on a fixed system of the divine order of things. Later he came to think of classification as merely an invention of man, much as the different orders of society are conventional and not real—all men, whether counted high or low in the social scale, being of one common clay. This led Buffon to his second period, when, as we have just seen, he declared that species less perfect, less active, and less armed are bound to disappear. This was the negative side. The positive was that species stronger and more active would succeed in the struggle for existence. Thus Old-World species transferred to the New World would have to transform themselves to fit their novel environment. Given an emigrant prince and an emigrant peasant, each would have equal opportunity as he stepped on the western shore. However it would not be long before it would appear who was the better man, the one used to habits of idleness, or the one used to habits of work. It would be case of paddle your own canoe, a case of sink or swim.

Buffon was the first naturalist whom Darwin puts among his forerunners. The next was Lamarck. He did an eminent service, explains Darwin, and that was in drawing attention to the probability that all change is the result of law and not of miraculous intervention. He suggested several means of modification. He attributed something to the direct action of the physical conditions of life, something to the crossing of already existing forms, and much to use and disuse, that is, to the effects of habit. The last factor is most important. Lamarck supposes that it explains "all the beautiful adaptations in nature, such as the long neck of the giraffe for browsing on the branches of trees."

Turning to Lamarck himself we find that he considers this last principle, that of habit, to be very important. He counted it a new view, in marked contrast to the old. The conclusion adopted up to the present, he explains, is that nature, or its Author, in creating animals has foreseen all possible sorts of circumstances in which they would be destined to live, and has given to each species a special organization, which forces each species to live in the places and climates where it is found, and there to preserve the habits which belong to it. My personal conclusion, he adds, is that nature in producing all the species of animals, from the most imperfect to the most perfect, has gradually completed this organization. . . . Thus each has received under the influence of the environment which it has encountered the habits which we recognize, and the modifications in its parts which observation reveals in it.

By emphasizing the effect of habit, Lamarck has killed two birds with one stone. These are the notion of final causes and the notion of fixed species. Animals are not created for a certain mode of life, but their mode of life had made them what they are. Wings were not given to birds in order to fly, but they grew wings in their efforts to fly.

Lamarck's rivals ridiculed his principle of effort, for several cases which he gave were rather overdrawn. He asserts that deer developed their horns by the efforts they made to butt their rivals; that snails grew feelers in front from the efforts to touch bodies ahead of them; that snakes sprang from reptiles with four extremities, owing to repeated efforts to elongate themselves in order to pass through narrow spaces.

These instances do seem fanciful. They remind one of certain modern advertisements with statements such as these: "Exert your will, develop your hidden powers, and you will be able to grow healthy, wealthy, and wise." But in all Lamarck's instances there was a grain of truth, declare many of his modern advocates, the new-Lamarckians, as they are called. At least the negative side appears to work. The lap dog has weakened its teeth because it is fed on soft food, while the blind fish in the Mammoth Cave has lost the use of its eyes because of the darkness. But the positive instances are much harder to prove. Certain mammals developed hoofs, explains Lamarck, because the habit of resting upon their feet during the greater part of the day has caused a thick horn to arise. Of course Lamarck did not hold that this could happen all at once. He did not make the mistake of Buffon that in a single generation great changes could be brought about. He was therefore obliged to give plenty of time and also the possibility of handing on these changes. Thus he declares: "For Nature time is nothing. It is never a difficulty; she always has it at her disposal, and it is for her the means by which she has accomplished the greatest as well as the least of her results. For all the evolution of the earth and of living beings Nature needs but three elements, space, time and matter."

It was a statement such as this that led Darwin to say that Lamarck did the eminent service of arousing attention to the probability of all things in both the organic and the inorganic world being the result of law and not of miraculous interposition. In other words, Darwin agreed with Lamarck's general conclusions, though not with his particular principles. He said that he started with the opinion that species are immutable, but at last (though it was like confessing a murder) he became convinced that they were not immutable. Yet Darwin does not believe in Lamarck's "adaptations from the slow willing of animals." "The will of organisms" could not account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life; for instance, the woodpecker or the tree frog to climb trees, or a seed for dispersal by hooks or plumes.

So Darwin declares that although the conclusions he is led to are not widely different from Lamarck's, the means of change are wholly so. To him external conditions, by themselves, accomplish very little. Rather the formation of a strong variety or species is almost wholly due to the selection of chance variations or variability.

§ 49. *Darwin and Lamarck*

It was the means, or ways, or methods of natural selection that led Darwin to differ from Lamarck. The Frenchman made a great deal of what is known as the psychic factor. It was the attempt to do certain things that led to the development of the necessary organs for the actions and the results of this were supposed to be handed on directly to the next generation. It is as if the village blacksmith endeavored to be strong and skillful in his trade, and having become strong and skillful, handed this on by heredity to his sons, and thus founded a family of strong and skillful blacksmiths. To this Darwin would demur. He was more cautious. His motto seemed to be that "many a mickle makes a muckle," and his working principle, "take care of the pennies, and the pounds will take care of themselves." Change in species could not come about suddenly, but, as he said, "is effected chiefly through the natural selection of numerous, successive, slight, favourable variations."

We now come to the third of the pioneers mentioned by Darwin. This was his own grandfather. Here the grandson said that it was "curious how largely Dr. Erasmus Darwin anticipated the views and erroneous opinions of Lamarck." The erroneous view meant was that the power of improvement rests with the animal's own efforts, the effects of these efforts upon the body being transmitted by inheritance.

The chief of the elder Darwin's arguments is this: wants awaken wishes, wishes bring about changes. Cattle, for example, in their search for food, have developed rough tongues to pull off the blades of grass. Hence this same "perpetual endeavour of the creatures to supply the want of food" would explain the growth of the pig's snout, the bird's beak, the elephant's trunk.

These are similar to the instances given by Lamarck, such as where deer, striving to run away from their enemies, developed fleetness. Now it was this resemblance between the Englishman's view and the Frenchman's that led Charles Darwin to consider them both wrong. They both attributed too much to effort, too little to accident. They both made too much of the animal's own want and wish, and too little of "the natural selection of numerous, successive, slight, favourable variations."

Countless cases of these slight variations, even of the most subtle kind, led Darwin to take up in the first chapter of his work the subject of artificial selection. Here he argues that nature offers the variation and man takes advantage of it—be he pigeon, poultry, or rabbit fancier. These men know that each race varies slightly and they win their prizes by selecting slight differences in the direction of improvement.

Slight variation, then, is the first principle in the origin of species. Another principle is the slowness of the process of change. Here Darwin should perhaps not have been so hard on his grandfather. The latter declares that the development of the pig's snout, the bird's beak, and the like, seems to have been gradually produced during many generations, by the perpetual endeavor of the creatures to supply the want of food, and to have been delivered to posterity with constant improvements for the purposes acquired.

This is a remarkable passage, and we shall find that Darwin himself agreed with two-thirds of it. He argued for gradual production, and for inheritance of acquired characteristics. He rejected the middle point, "the endeavour of the creature." This was too much like Lamarck's prime principle of effort, a principle of explanation which later became the great rival of Darwin's prime principle of natural selection.

This introduces us to the next of the predecessors of evolution mentioned by Darwin. This was Geoffroy St. Hilaire, Lamarck's colleague in the great botanical gardens of Paris. Geoffroy, says Darwin, was convinced that the same forms have not been perpetuated since the beginnings of things. For change, then, he relied chiefly on the conditions of life, or "the surrounding world," as the cause of change. But he was cautious in drawing conclusions, and did not believe that existing species are now undergoing modifications.

Turning to Geoffroy's works, we find that by the surrounding world he meant what we should call the influence of environment. For example, he thus explained how crocodiles became amphibious, that is, living both in the water and on land. Their remote ancestors, the saurians, first lived in the water. Some of them happened to crawl on the land, stranded perhaps on the muddy banks of some river. Now the atmosphere, argues Geoffroy, acting upon the lung cells, brings about modifications which are favorable or destructive. These are inherited, and they will influence all the rest of the organization of the animal, because, if these modifications tend to injurious effects, the animals which exhibit them perish, and are replaced by others of a somewhat different form, a form changed so as to be adapted to the new environment.

This line of reasoning evidently appealed to Darwin. It was a more moderate theory than that of the other two French pioneers. Buffon had made the influence of environment too rapid. For example, Old World species transferred to the New World would change speedily, according to his view. Lamarck, relying on the effort of the animal, had imagined decided changes brought about in a few generations. For example, a shore bird striving to catch its food in the water soon develops longer legs and becomes a wader. But Geoffroy made the chief factor not effort but the action of surrounding conditions, such as air, and he made the actions of these conditions very slow and gradual.

Darwin himself did not fully follow any of these Frenchmen—Buffon, Lamarck, or Geoffroy St. Hilaire. He declared that neither "the action of the surrounding conditions," nor "the will of organisms" could account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life.

If neither environment nor effort will explain the gradual changing of species, what will? The chief Darwinian answer is—natural selection. The first recognition of this principle, Darwin goes on to say, was made by an Englishman, Dr. W. C. Wells, who, in 1813, read before the Royal Society a paper entitled, "An Account of a White Female, Part of Whose Skin Resembles That of a Negro." Darwin gives as the gist of this paper that Dr. Wells, after remarking that negroes and mulattoes enjoy an immunity from certain tropical diseases, observes, firstly, that all animals tend to vary in some degree, and, secondly, that agriculturalists improve their domesticated animals by selection. In other words, what is done in the latter case by art, seems to be done with equal efficacy, though more slowly, by nature, in the formations of varieties of mankind, fitted for the country which they inhabit. Of the accidental varieties of man, which would occur among the first few and scattered inhabitants of the middle region of Africa, some one would be better fitted than the others to bear the diseases of the country. This race would consequently multiply, while the others would decrease; not only from their inability to sustain the attacks of disease, but from their incapacity of contending with their more vigorous neighbors. The color of this vigorous race is taken for granted, from what has already been said, to be dark. But the same disposition to form varieties still existing, a darker and a darker race would in the course of time occur; and as the darkest would be the fittest for the climate, this would at length become the most prevalent, if not the only race, in the particular country in which it had originated.

This is a remarkable passage, and the part of it that Darwin thought the most remarkable concerned the accidental variations among human beings which would make some better fitted than others to bear the diseases of the country. Darwin gives full credit to this anticipation of his own central principle of natural selection, but he states that it was only called to his attention by an American after the first edition of the *Origin of Species* appeared.

There were also two other anticipators of this principle, one a small man and the other a great. The first was a certain Patrick Matthew, who claimed that new forms may be generated "without the presence of any former mould or germ." Matthew's views were put in an obscure journal and were not fully carried out, yet he later advertised himself as the discoverer of the principle of natural selection. Now it is one thing to have an idea, another to bring it successfully before the world and to back it up with evidence. This was really accomplished by the great naturalist Alfred Wallace, who is known as the co-discoverer of the principle of natural selection, along with Darwin himself. The two men announced their discovery at the same moment, each giving generous credit to the other. It was indeed a fine example of team play and sportsmanship in science.

Of the other anticipators of Darwinism we need speak but briefly. Darwin gives them all the credit possible, for he is always conscientious and painstaking in offering the complete evidence. But the credit does not amount to so much since all the minor men mix the good with the bad. They had some inklings of the workings of evolution, but alongside of these they put curious notions, quite different from Darwin's own. Thus Rafinisque holds that all species might have been varieties once, except the original types or ancestors. This is what is called preformationism, or the belief in previous fixed forms. It is opposed to transformation, or thoroughgoing change of form. As Darwin himself put it: Grant a simple archetypal, or original creature, like the mudfish, with the five senses and some vestige of mind, and I believe natural selection will account for the production of every vertebrate animal.

§ 50. *Natural Selection*

It needed many hands to make evolution go, but in this case many hands did not make light work, for it took Darwin some twenty years to find a real working hypothesis, that of natural selection. He is the acknowledged genius who made the whole a success. At the same time he is generous towards the contribution of others. He points out that a dozen or more men before him had had similar thoughts. Greeks, Germans, French, English, Americans—all had valuable suggestions leading towards the final result. But it was Darwin, the hard-working Englishman, who had been gathering data for half a century, and it was he, the great generalizer, who put the finishing touch to all by assembling the parts in a single structure.

Thus the making of a working hypothesis is like the construction of a successful machine. The materials are brought from various sources before they are finally assembled in the factory. Woods from the forest, steel from the blast furnaces, rare metals from the laboratory, rubber from overseas, finally the gasoline from the refinery—all pour in from different directions, are sorted, worked over, assembled, and with the magic of the electric spark, the machine starts off under its own power. In the case of Darwin he was more than the brain factory which gave the final touch. Indeed it was his brain that gathered the raw materials, assembled the parts, and added that final something—an efficient cause. Others had described the various kingdoms of living nature; others had guessed that this or that might explain the change from one species to another, but none of these explanations worked. The push of the prime mover of Aristotle, the internal perfecting principle of Leibnitz, the effort of the organism of Lamarck, none of these were satisfactory. They looked well on paper, they did not work in practice. The prime mover was too remote, the perfecting principle did not account for imperfection, the principle of effort was too fantastic—wishes are one thing, obstacles are another. But natural selection is not remote, it is going on here and now; it accounts for imperfection because it sifts out the imperfect; it is not fantastic, because it depends on ordinary events. In nature there is a constant struggle between living beings, from quarrels in the nursery to wars between nations. In nature, too, there is a survival of the fittest, in the sense that those best fitted live, while those unfitted perish. The fittest does not necessarily mean the best in any moral sense. In warfare the pestilent germ may survive in the mud of the trenches, while the soldier succumbs to disease.

Natural selection, then, explains when other theories do not. The prime mover and his plans may appeal more to the imagination; the perfecting principle may encourage greater hope; but natural selection seems better to describe things as they are—a universe of beings, struggling, fighting, jostling one another, from the Amazonian forest to Wall Street and the business world.

This is anything but a pleasant picture—such was the first reaction of the mid-Victorian mind. It made nature "red with tooth and claw," said the poet laureate. It was not only unpleasant, it was downright cruel, declared the humanitarian. But it was true, retorted the scientist. Thus Malthus showed that over-population led to checks like undernourishment and disease, and the pressure of populations to wars between nations. Darwin took this hint and applied it to all living creatures, from fish crowding the seas to families crowding the slums. However you gloss it over, the principle is there. In war, the beat of the drum and the flying of flags, the brass band and appeals to patriotism may make the fight seem glorious. The glory is one thing, the firing line another. There is little romance in muck and filth, in battle and sudden death. (& — mutilation.)

Naturally the humanitarian did not like this outcome of natural selection. Stripped of its trappings, in all its nakedness, it was a disheartening doctrine. Darwin himself was the kindliest of men, but his house full of pets and his garden of flowers furnished the very materials on which his doctrine was based. Domestic animals and the kindly fruits of the earth, when you come to examine them, simply go to prove survival values. The strong survive, the weak perish. The cat swallows the canary, and weeds choke the flowers.

The term "struggle for existence," although used in a large sense, explained Darwin, cannot hide what really takes place. A plant on the edge of a desert may be said to struggle for life against the drought; the mistletoe, to struggle against the apple tree upon which it is a parasite. But these are only far-fetched examples. The real battle for life comes when organic beings are exposed to severe competition. Take the case where in Yorkshire the ancient black cattle were displaced by the long-horns, and where these, in turn, "were swept away by the short-horns as if by some murderous pestilence." So, continues the naturalist, we may admit in words the truth of the universal struggle for life, but we must always keep in mind what actually happens; we behold the face of nature bright with gladness, we often see superabundance of food; we do not see, or we forget, that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestlings, are destroyed by birds and beasts of prey.

These statements call for a certain modification. The modern evolutionist is inclined to think that Darwin overestimated the importance of individual variations and that only variations that are in the nature of mutations are efficient in the transmutation of species. Otherwise the argument is still considered valid. In this qualification mutation means a suddenly occurring rearrangement of the germ plasm, resulting in the production of an essentially different material from what it was before. The differences may be minute or considerable in amount, but they are in all cases essential changes from the original condition. For example, the red-eyed fruit fly suddenly gives rise to a white-eyed offspring which, if inbred, breeds true to its changed color. In other words, the present-day attitude towards natural selection is that it does not lead to the formation of new species through the summation of minute variations. New species come into existence probably by mutation and then natural selection determines whether they are fit to survive or not. In short, natural selection is a conservative rather than a radical tendency, it tends to eliminate extremes and to maintain an average. The problem as to whether germ plasm can by modified by external conditions is still an unsettled problem. (In 1926, yes. Now, no.)

§ 51. *The Great Tree of Life*

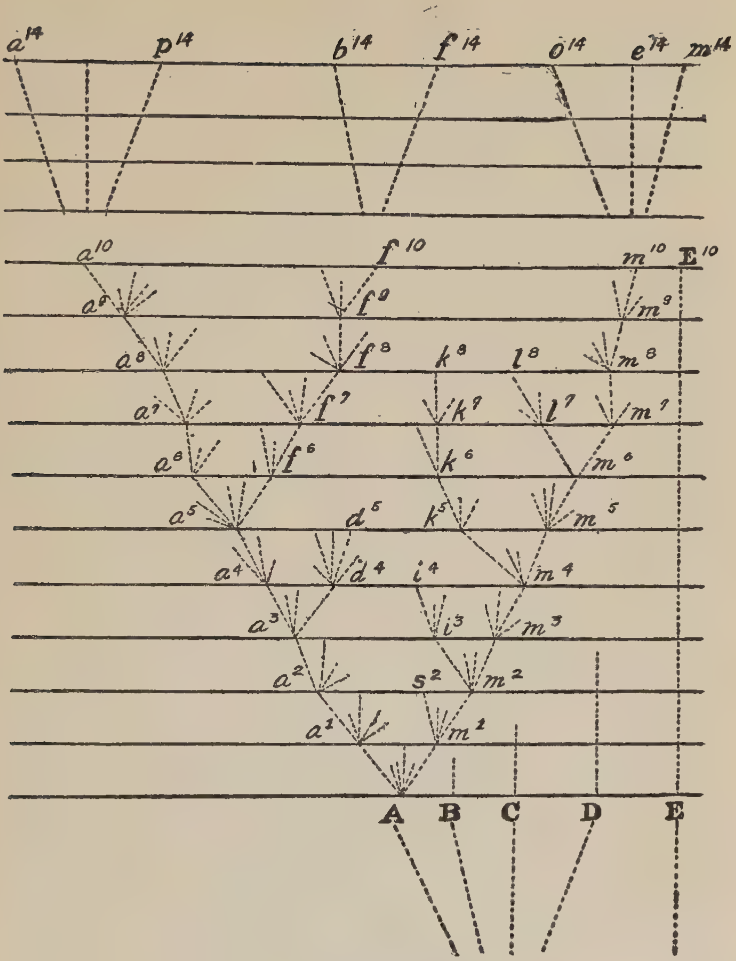
Natural selection and the struggle for existence are now household words. The results of that selection and that struggle in the way of scrapping the old forms of life are not hard to grasp. Darwin himself has made it clear in a diagram which he calls "the great tree of life." Here the green and budding twigs may represent existing species, and those produced during former years, the long succession of extinct species. At each period of growth all the growing twigs have tried to branch out on all sides, and to overtop and kill the surrounding twigs and branches, in the same manner as species and groups of species have at all times overmastered other species in the great battle for life.

But this is not all. The limbs which are divided into great branches, and these into lesser and lesser branches, were themselves once, when the tree was young, budding twigs. Still further, the tree was at one time a mere bush. Now of the many twigs which flourished at that remote period, only two or three, now grown into great branches, yet survive and bear other branches. This is because, from the first growth of the tree, many a limb and branch has decayed and dropped off. Finally, we may see here and there a thin, straggling branch sprung from a fork low down in the tree, and which by some chance has been favored and is still alive on its summit.

What is the meaning of this description? The green and budding twigs, as Darwin says, represent existing species, the dead branches extinct species, and the long, thin, struggling branches, some curious survivals from remote ages, such as that strange egg-laying mammal, the Australian duckbill.

Now this great tree of life in natural history is like a family tree among men. One ancestor, like A in the Darwinian diagram, has come to a new country. He has had several sons and daughters. Some of these have died without issue, and that "branch of the family," as the saying is, has died off. These are the extinct species. But the family still multiplies, and generation after generation the chart is filled out with new names. But some of these new branches are stronger than others, and the family tree has a lop-sided appearance, because some of the descendants of the founder have gone ahead in the world. Consider, then, a grand family reunion in the tenth generation. All who attend are cousins to some degree, but what a difference in appearance, ability, and prosperity! In this family round-up the city cousin may look down on the country cousin, but let the former consider that chance, accidents of fortune, changes in environment and what not have all played their part. Some have gone West and prospered. Some have stuck in the East and preserved the family name but not the family fortune. The latter with their old-fashioned ways and unprogressive methods may stand for those thin, straggling branches sprung from a fork low down in the tree.

So far all is fairly clear, but as Darwin says, the circumstances favorable to the production of new forms through natural selection is an extremely intricate subject. Un-



THE GREAT TREE OF LIFE

less favorable variations be inherited by at least some of the offspring, nothing can be effected by natural selection. Then, too, the tendency to reversion may often check or prevent the work. This may be seen in what a florist calls a "throwback," where, for example, a small, ugly, yellow blossom reappears on a fancy pink chrysanthemum plant.

Besides reversion, there is intercrossing to check steady progress. In the case of artificial selection, the breeder selects for some definite object, and if the individuals be allowed freely to intercross, his work will completely fail. He would not be such a fool as to let the race horse and the cart horse interbreed. But in nature at large there is no such methodical selection, any more than in human nature. People do not ordinarily give much thought to the principles of eugenics when it is a question of "love at first sight," or "marrying for money," or other motives, sentimental or sordid.

Natural selection, therefore, as distinguished from artificial, is a haphazard affair, and it is a wonder that nature, with all the mischances of circumstance, has succeeded in progressing at all. And yet, as Darwin contends, there is progress under the principle of variability. Given the tendency to differ, "all the individuals varying in the right direction, though in different degrees, will tend to be preserved." The principle of divergence, causing differences at first barely appreciable, tend steadily to increase. This at least holds true in the case of the productions of man, as when at an early period of history the men of one district required swifter horses, while those of another required stronger and bulkier horses. This principle of divergence caused the breeds to diverge in character, both from each other and from their common parent.

But how, asked Darwin, can this principle apply in nature? He confesses that it was a long time before he saw how it could apply, but at last he came to the conclusion that the more diversified the descendants from one species, the more chances they would have to survive. Take the case of a meat-eating animal. If its structure, constitution, and habits are changed, it can seize on places at present occupied by other animals. Some of the new varieties could feed on new kinds of prey, either dead or alive, some could inhabit new stations, climbing trees, frequenting water, and some, perhaps, becoming less carnivorous.

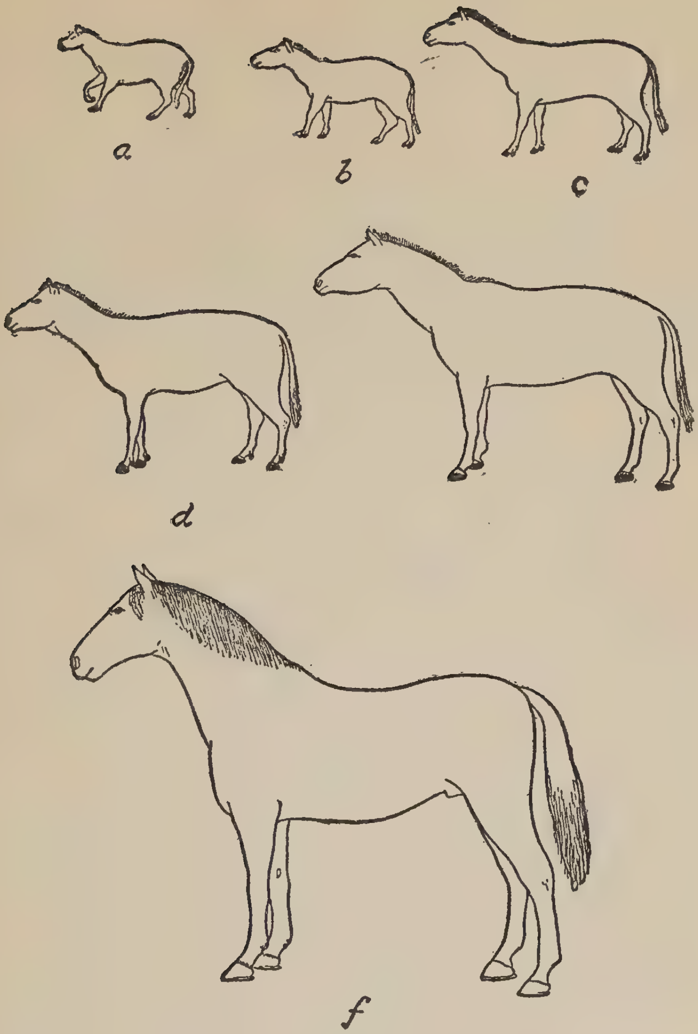
Just as variety is the spice of life, so diversity is the means of survival. Hence, as Darwin says, what applies to one animal will apply throughout all time to all animals—that is, if they vary, for otherwise natural selection can effect nothing. Thus it will be with plants. It has been experimentally proved that if a plot of ground be sown with one species of grass, and a similar plot be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can be raised in the latter than in the former case.

Against the doctrine of the diversity of structure might be brought the charge that the jack of all trades is master of none. Quite the contrary, asserts Darwin. Diversity means a kind of division of labor among the different organs of the highly organized. A set of animals with their organization but little diversified could hardly compete with a set more perfectly diversified in structure. A creature that can adapt itself to changing conditions is bound to succeed, like the pioneer who is backwoodsman, hunter, and farmer, as new conditions arise. The thing is illustrated on what was once our western frontier, where on the same piece of property may be seen the log cabin, the frame house, and the brick mansion of the successive generations of a successful family.

But to return to Darwin himself. Natural selection, like a savings bank account, acts by the preservation and accumulation of variations, which are beneficial to the creature, whatever the conditions it is exposed to at all periods of life. Like the thrifty founder of a family who started a fund, the original deposit, even at low compound interest, is always a standby for a rainy day. Or as Darwin puts it: natural selection acts through one form having some advantage over other forms in the struggle for existence. Hence it will chiefly act on those which already have some advantage. Here the largeness of any group shows that its species have inherited from a common ancestor some advantage in common.

So much for the successes. Now for the failures in the struggle for existence. As time goes on the large group will split up into smaller. Then the latter, the more highly perfected sub-groups, will tend to supplant and destroy the earlier and less improved sub-group, and the latter will finally disappear.

This is illustrated in the history of the horse. Under its various technical names—eohippus, protorohippus, and the like—we have a kind of geological moving picture, where the earlier generations fade away into the later. The earliest ancestor of the horse was a creature not much larger than the domestic cat. It had four toes and a "splint" of the first digit. As development went on, the



THE HORSE (*f*), AND ITS REMOTE ANCESTORS (*a-e*) side toes, like the "dew nails" on a dog's leg, worked up the leg as they became mere useless appendages. Meanwhile the legs grew longer and the animal larger and swifter.

The record of the rocks, especially from the Bad Lands of the western states, has given us a proof which Darwin did not possess. In his day he confesses that the record was "vastly imperfect." Yet our present knowledge only fulfills his prophecy that the later and more highly perfected sub-group will constantly tend to supplant the earlier and less improved sub-groups.

§ 52. *The Difficulties of Darwinism*

In combating the theory of special creation or supernatural selection, Darwin was able to criticize his own principle of natural selection. Like the honest scientist that he was, he wishes to test his own work according to his own principles. It would be a waste of labor to put forward something that was unfit to survive.

Now what manner of man was this special creationist of Darwin's day? This picture is given of him in the *Origin of Species:*

> He who believes that each being has been created as we now see it, must occasionally have felt surprise when he has met with an animal having habits and structure not in agreement. What can be plainer than that the webbed feet of ducks and geese are formed for swimming? And yet there are upland geese with webbed feet which rarely go near the water. . . . He who believes in separate and innumerable acts of creation may say, that in these cases it has pleased the Creator to cause a being of one type to take the place of one belonging to another type; but this seems to me only restating the fact in dignified language. He who believes in the struggle for existence and in the principle of natural selection will acknowledge that every organic being is constantly endeavoring to increase in numbers; and that if one being varies ever so little, either in habits or structure, and thus gains an advantage over some other inhabitant of the same country, it will seize on the place of that inhabitant, however different that may be from its own place. Hence it will cause

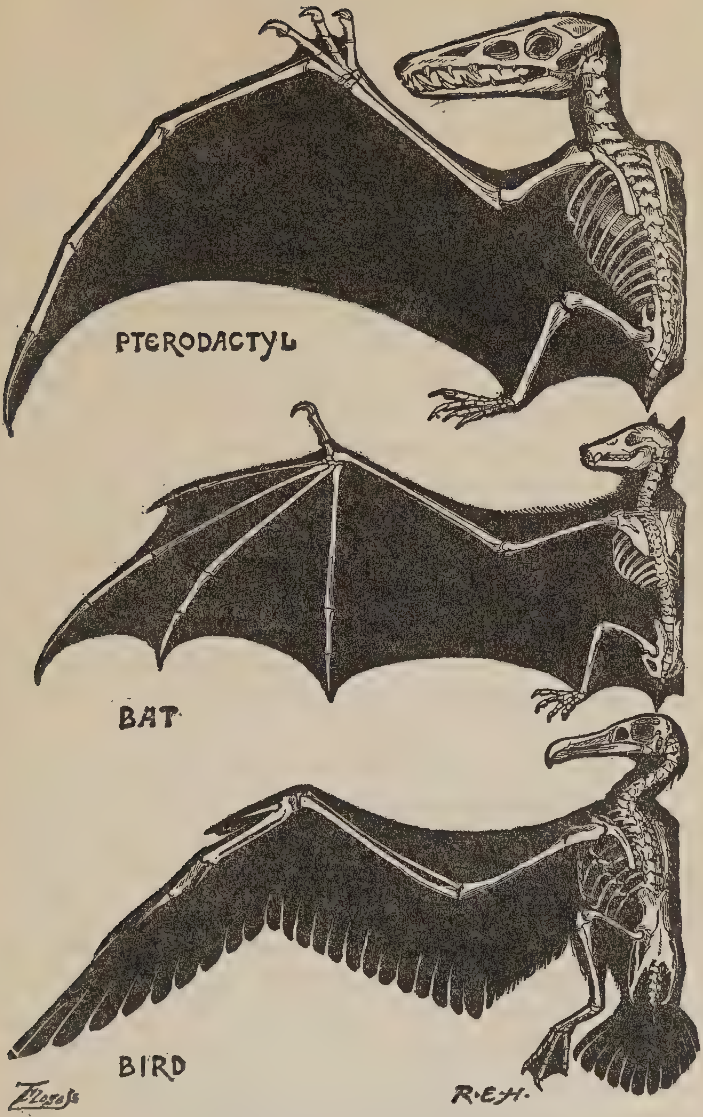
> him no surprise that there should be geese and frigate-birds with webbed feet, living on dry land and rarely alighting on the water, that there should be long-toed corn crakes, living in meadows instead of in swamps; that there should be woodpeckers where hardly a tree grows.

In drawing this picture of the special creationist, Darwin has in mind the kind of difficulty that the people of his day would have in accepting his conclusions. So he goes on to say that long before the reader has arrived at this part of his work, a crowd of difficulties will have occurred to him. These difficulties and objections may be enumerated as follows:

First, why, if species have descended from other species by fine gradations, do we not everywhere see innumerable transitional forms? Why is not all nature in confusion, instead of the species being, as we see them, well defined?

Secondly, is it possible that an animal having, for instance, the structure and habits of a bat, could have been formed by the modification of some other animal with widely different habits and structure? Can we believe that natural selection could produce, on the one hand, an organ of trifling importance, such as the tail of the giraffe, which serves as a fly-flapper, and, on the other hand, an organ so complicated and wonderful as the eye?

Thirdly, can instincts be acquired and modified through natural selection? What shall we say to the instinct which leads the bee to make cells, and which has practically anticipated the discoveries of profound mathematicians?



ILLUSTRATIONS OF GROUP RELATIONSHIP

Fourthly, how can we account for species, when crossed, being sterile and producing sterile offspring, whereas when varieties are crossed, their fertility is unimpaired in the offspring?

Let us take up the solution of some of these difficulties. The first refers to the absence or rarity of transient forms, or what we now call missing links. Each new form tends to take the place of and finally to exterminate its own less improved parent form. Hence if we look at each species as descended from some unknown form, both the parent and all the transitional varieties will generally have been exterminated by the very process of the formation and perfection of the new form. But, as by this theory innumerable transitional forms must have existed, why do we not find them embedded in countless numbers in the crust of the earth? The answer mainly lies in the record being incomparably less perfect than is generally supposed. The crust of the earth is a vast museum; but the natural collections have been imperfectly made, and only at long intervals of time.

This answer seems adequate. It is like the motor car of this year's model supplanting that of the years before, and like trying to reconstruct the original parent model of the automobile by digging for lost parts in a city dump heap.

Next, as to the second difficulty concerning beings with peculiar habits and structures. Look at the family of squirrels, says Darwin. Here we have the finest gradations from animals with their tails only slightly flattened, from others with the skin on their flanks rather full, to the so-called flying squirrel. The latter have their limbs and even the base of the tail united by a broad expanse of skin, which serves as a parachute and allows them to glide through the air to an astonishing distance from tree to tree.

These are positive cases of creatures with peculiar structure adapted to their environment. Others are found in birds which use their wings as flappers, like the loggerheaded duck; as fins in the water, and as front legs on the land, like the penguin; as sails, like the ostrich, and so on. The structure of each of these birds is good for it, under the conditions of life to which it is exposed, for each has to live by a struggle.

All these are positive cases of peculiar habits and structures, gained by useful modifications and by the accumulative effects of the process of natural selection. They do not need acts of special creation for their explanation. Much less do the negative cases, such as upland geese with webbed feet who rarely go near the water, and woodpeckers where hardly a tree grows.

The next objection to be met is this: How can natural selection produce organs of such trifling importance as the tail of the giraffe which serves as a fly-flapper and, on the other hand, an organ so wonderful as the eye? The answer to the first is, that the tail of the giraffe is not of such trifling importance, for the existence of cattle and other animals absolutely depends on their power of resisting attacks of insects.

But to go from organs of little apparent importance to those of extreme perfection and complication such as the eye. Darwin freely confesses that to suppose that the organ of vision with all its contrivances for adjusting the focus to different distances, for diffusing different amounts of light, could have been formed by natural selection, seems absurd in the highest degree. As he puts it:

When it was first said that the sun stood still and the world turned around, the common sense of mankind declared the doctrine false; but the old saying that the voice of the people is the voice of God, as every philosopher knows, cannot be trusted in science. Reason tells me, that if numerous gradations from a simple and imperfect eye to one complex and perfect can be shown to exist, each grade being useful to its possessor, as is certainly the case; if further, the eye varies and the variations be inherited, as is likewise certainly the case; and if such variations should be useful to any animal under changing conditions of life, then the difficulty of believing that a perfect and complex eye could be formed by natural selection, though insuperable to our imagination, should not be considered as subversive of the theory.

But to take the contrary supposition that the eye was a special creation made in the manner of a telescope. We know that this instrument has been perfected by the long-continued efforts of the highest intellects, but have we any right to assume, inquires Darwin, that the Creator works by intellectual powers like those of man? If we must compare the eye to an optical instrument, we must suppose that there is a power, represented by natural selection or the survival of the fittest, always intently watching each slight change in the transparent layers and carefully preserving each one which tends to produce a more distinct image. In addition we must suppose each new state of the instrument to be multiplied by the million; each to be preserved until a better one is produced, and then the old ones to be all destroyed. In living bodies, variation will cause the slight alterations, generation will multiply them almost infinitely, and natural selection will pick out with unerring skill each improvement. Let this process go on for millions of years, and during each year on millions of individuals of many kinds; and may we not believe that a living optical instrument might thus be formed as superior to one of glass as the works of the Creator are to those of man?

§ 53. *More Difficulties*

Darwin has taken the most difficult case he could think of, that of the human eye, and has shown how natural selection works in its evolving. Yet there is more than one kind of eye. There are organs of vision ranging from that of the mollusk to that of the eagle. Some authors have maintained that such organs have been formed for the sake of mere variety, almost like toys in a shop. But this view of nature, asserts Darwin, is incredible. The same end of adaptation to environment has been reached by different means, the same functions performed by organs different in development. In the vegetable kingdom especially we may pass through an inexhaustible number of contrivances all for the same purpose but entailing changes in every part of the flower. Thus the honey may be stored in variously shaped receptacles, sometimes forming traps for insects which are devoured by the plant, sometimes forming structures which serve for fertilization. A certain orchid has part of its lower lip hollowed out into a bucket. Crowds of humblebees visit this orchid. In doing this, as observed by one naturalist, they frequently pushed each other into the bucket, and their wings being wetted, they could not fly away, but were compelled to crawl out through the passage formed by the spout or overflow. To make a long story short, this was all contrived to make the bee, with pollen glued to its back, carry this pollen away and fertilize another orchid.

The most ingenious man, adds Darwin, if he had not witnessed what takes place, could never have imagined what purpose all these parts of the plant serve. For such a complicated structure, then, we are obliged to infer that every highly developed organism has passed through many changes, and that each modified structure tends to be inherited. This is in order that each modification will not be quite lost, but may be again and again further altered. In short, natural selection acts only by taking advantage of slight successive variations in relation to changed habits and conditions of life.

But some naturalists, Darwin acknowledges, have protested against this utilitarian doctrine. This doctrine of usefulness means that every detail of structure has been produced for the good of its possessors. They believe that many structures have been created for the sake of beauty, or to delight man, or the Creator, or for the sake of mere variety. Such doctrines, if true, would be absolutely fatal to his theory, admits Darwin. So he briefly disposes of these objections. To take them in reverse order. Creation for the sake of variety would turn nature into a toy shop, as he has already said. Creation for the sake of delight to the Creator is beyond the scope of scientific discussion. But the first point must be discussed, for it would be subversive of the whole theory of natural selection. Many believe that organic beings have been created beautiful for the delight of man. If so, it ought to be shown that before man appeared there was less beauty on the face of the earth than since he came upon the stage. Were the beautiful fossil shells created in order that man ages afterward might admire them in his cabinet? Again, flowers rank among the most beautiful productions of nature, but this is simply in order that they may be easily observed by insects. It is an invariable rule that when a flower is fertilized by the wind, it never has a gayly colored corolla. Such are the poor flowers we see on grasses, docks, and nettles, on fir, oak, nut, and ash tree. Gayly colored berries have beauty, but this beauty serves merely as a guide to birds and beasts, in order that the fruit may be devoured and the manured seeds scattered about.

Darwin has here been criticized for being more practical than poetical, and the problem of beauty in general still remains unsolved by him. The very cases he mentions, such as fossil shells with their symmetry of form, would have been used by some Greek thinker to show that the creative spirit of the cosmos was a spirit of beauty. Further we know that the classic sculptors used not only shells but common plants for their decorative designs.

Besides the mineral and the vegetable, Darwin has the animal kingdom to account for, and here he brings forward an argument that still seems weak to many. He admits that a great number of male animals, as all our most gorgeous birds, some fishes, reptiles and mammals, and a host of magnificently colored butterflies, have been rendered beautiful for beauty's sake. But this has been effected he claims, through sexual selection, that is, by the more beautiful males having been continually preferred by the females, and not for the delight of man.

Darwin's theory of sexual selection among animals has been attacked, and when it comes to the highest of the animals, man, it appears to fail. At any rate among the most highly civilized modern races, the female of the species is more gorgeous than the male. Furthermore, if we go back to the savage, it would seem that it is not beauty but strength that wins. According to the popular novels, and as is so often portrayed on the screen, the caveman generally comes to his own, not by his beauty, but by his bludgeon. Here Darwin himself puts the savage near the brute. Generally the most vigorous males, those which are best fitted for their places in nature, will leave the most progeny. A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. But even here, he confesses, sexual selection is less rigorous than natural selection.

These things are among the special difficulties of the theory of natural selection, but even with these difficulties, we find, in casting up the account, that the balance is in Darwin's favor. He has accounted for beings with peculiar structure, like the flying squirrel; for organs of extreme complication, like the eye; for organs of little apparent importance, like the giraffe's tail. But above all, there is the great tree of life and the wonderful fact we are apt to overlook from familiarity, the fact that all animals and all plants throughout all time and space are related to each other in groups.

§ 54. *The Descent of Man*

The great tree of life shows that all animals, throughout all time and space, are related to each other in groups. This being so, why should not man, the highest of the animals, come under the common laws of evolution, of descent by adaptative modifications? Darwin grants that our pride may revolt at the thought of man, "the wonder and glory of the universe," having branched off from a group of Old World monkeys, for while this may have given a pedigree of prodigious length, it cannot be said to be one of noble quality.

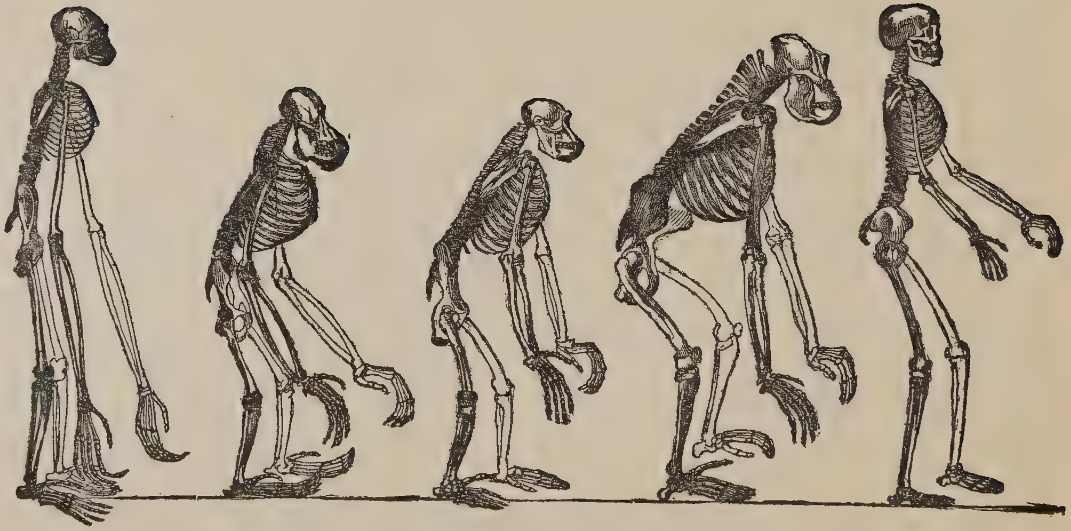
However, we must swallow our pride and see where logic leads us. Man is the co-descendant, with other species, of some ancient, lower, and extinct form. The evidence for this is of three kinds. There is a similar bodily structure, a similar manner of development, and many vestigial and rudimentary structures like the vermiform appendix, which, as has been said, make the human body a veritable museum of rare and interesting relics of antiquity.

Technically these arguments are known as the arguments from homology, from embryology, and from rudiments. The first means that man is constructed on the same general type or model as other mammals. Thus all the bones in his skeleton can be compared with corresponding bones in a monkey, bat, or seal. So is it with his muscles, nerves, blood vessels, and internal viscera.

The brain, the most important of all the organs, follows the same general law. Even a hostile witness of Darwin's day admits that every chief fissure and fold in the brain of man has its analogy in that of the orang, though at no period of development do their brains perfectly agree, for otherwise their mental powers would be the same.

This correspondence of relationship is further shown by other curious facts. Man is liable to receive from the lower animals and to communicate to them certain diseases, such as hydrophobia and cholera. Monkeys are liable to many of the same non-contagious diseases as we are, from catarrh to cataract. Medicines produce the same effect on them as on us. Many kinds of monkeys have a strong taste for tea, coffee, and spirituous liquors. These trifling facts, concludes Darwin, prove how similar the nerves of taste must be in monkeys and man, and how similarly their whole nervous system is affected. To this may be added the recent corroborative proof that the anthropoid apes are closest akin to man both in the chemical composition of their blood and in the physiological reactions of their glands.

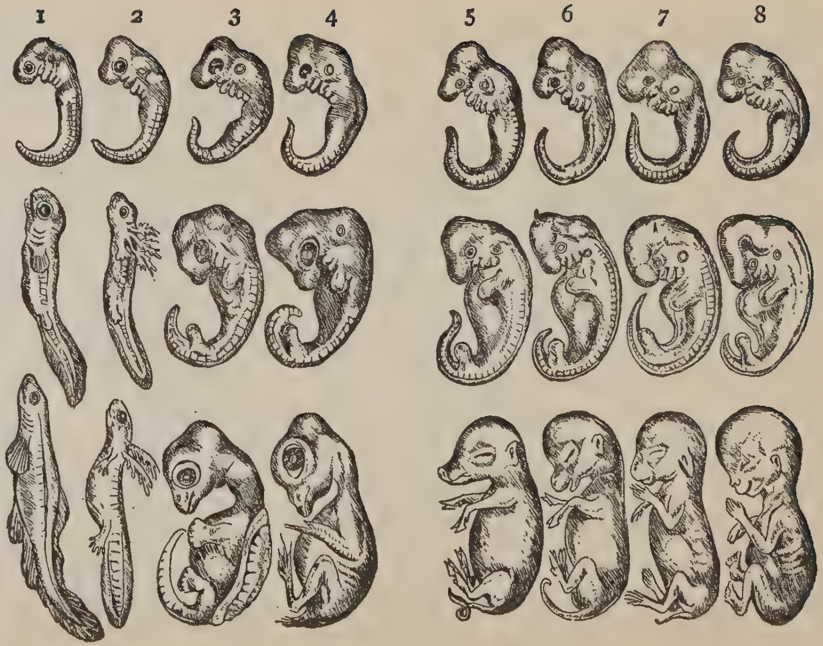
Such, briefly, is the argument from homology or similarity of structure between man and the lower creatures. The next argument, that from embryology, is more striking. As Huxley says, man's place in nature is in close relationship with the lower orders. He does not originate in a different way from a dog, a bird, a frog, or a fish. And not only the mode of origin but the early stages of development of man are identical with those of the animals below him in the scale. The feet of lizards and mammals, the wings and feet of birds, no less than the hands and feet of man, all arise from the same funda-



SKELETONS OF GIBBON, ORANG, CHIMPANZEE, GORILLA, AND MAN (READING FROM LEFT TO RIGHT) mental form. A study of the diagram will show all this and more too. The human embryo resembles a fish in heart, brain, and backbone, resemblances which point to a community of ancestry. In addition there are the curious facts as to rudimentary organs in man, both before and after birth. Thus in the human embryo the end of the spine shows a projection like a true tail. It has no function, but it plainly represents this part in other animals. In a few rare cases human beings have been born with a tail that may grow to eight or ten inches. More familiar than these are certain rudimentary functions of childhood and mature life. Thus the infant is bow-legged at birth, the curved position of its limbs being like that of a gorilla. It has other ape-like characteristics, such as a highly flexible great toe and a clasping power of the hands that enable it to support its own weight for as long as two minutes.

And there are other cases of absolutely useless faculties derived from our remote human progenitors. Such are occasional instances of men who can move their ears or their scalps, or where they even possess certain muscles which point to an original four-footed gait, muscles which have reappeared only after many thousands of generations. There are, finally, more familiar and more useless parts which point back to a common linkage between man and his lower ancestors. Such are wisdom teeth, which are tending to disappear in the more civilized races, and that troublesome vestigial remain, the vermiform appendix, a shortened rudiment in man, but extremely long in many of the lower herbivorous animals.

These are a few of the arguments from embryology and the rudiments. Taken with the arguments from



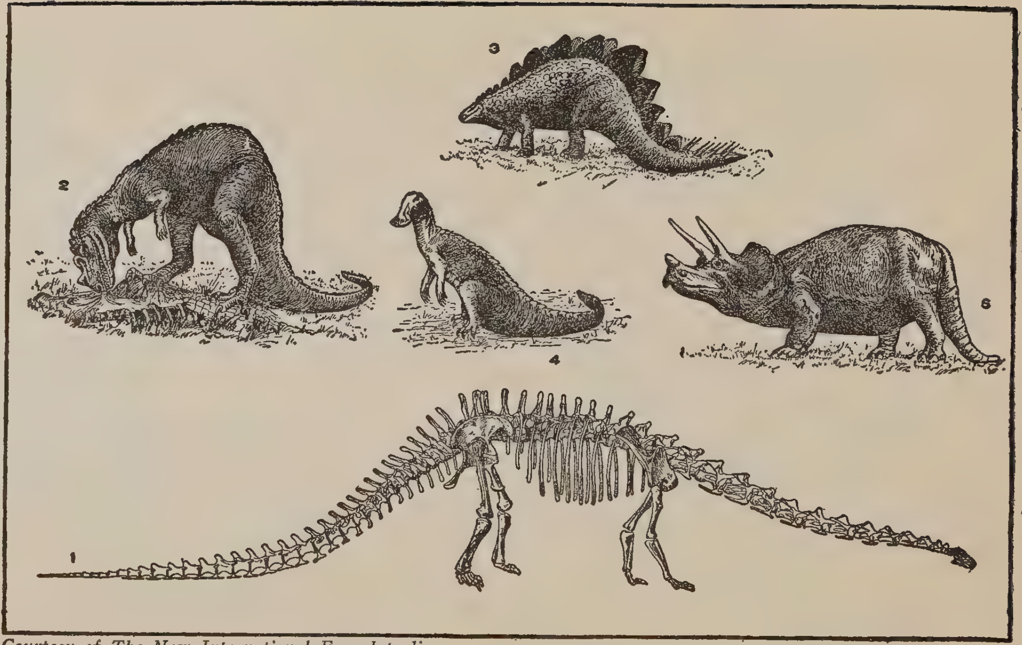
THREE STAGES OF DEVELOPMENT IN THE EMBRYOS OF (1) FISH; (2) SALAMANDER; (3) TORTOISE; (4) CHICK; (5) HOG; (6) CALF; (7) RABBIT; (8) MAN common bodily structure they lead Darwin to this conclusion, namely, that the homological construction of the whole frame in the members of the same class is intelligible, if we admit their descent from a common progenitor, together with their subsequent adaptation to diversified conditions. On any other view, the similarity of pattern between the hand of a man or monkey, the foot of a horse, the flipper of a seal, and so forth, is utterly inexplicable. It is no scientific explanation to assert that they have all been formed on the same ideal plan. With respect to development, we can clearly understand, on the principle of variations supervening at a rather late embryonic period, and being inherited at a corresponding period, how it is that the embryos of wonderfully different forms should still retain, more or less perfectly, the structure of their common progenitor. No other explanation has ever been given of the marvelous fact that the embryos of a man, dog, seal, bat, and reptile can at first hardly be distinguished from each other. In order to understand the existence of rudimentary organs, we have only to suppose that a former progenitor possessed the parts in question in a perfect state, and that under changed habits of life they became greatly reduced, either from simple disuse, or through the natural selection of those individuals which were least encumbered with a superfluous part. Thus we can understand how it has come to pass that man and all the other vertebrate animals have been constructed on the same general model, why they pass through the same early stages of development, and why they retain certain rudiments in common. Consequently we ought frankly to admit their community of descent. To take any other view is to admit that our own structure, and that of all the other animals around us, is a mere snare laid to entrap our judgment. This conclusion is greatly strengthened if we look to the members of the whole animal series, and consider the evidence derived from their affinities, their classification, their geographical distribution, and geological succession. It is only our natural prejudice, and that arrogance which made our forefathers declare that they were descended from the demi-gods, which leads us to demur in this conclusion. But before long the time will come when it will be thought wonderful that naturalists, who were well acquainted with the comparative structure and development of man and other mammals, should have believed that each was the work of a separate act of creation.

§ 55. *The Attack on Darwinism*

Darwin says that for many years he collected notes on the origin or descent of man, without any intention of publishing on the subject, but rather with the determination not to publish, as he thought that he should thus only add to the prejudices against his views. His caution was justified. The *Descent of Man* underwent a "fiery ordeal," and the fight between the evolutionists and anti-evolutionists became a veritable battle royal.

In the first edition of the *Origin of Species* the author had hinted that through natural selection light would be thrown on the origin of man and his history. Meanwhile in the ten years between the two books, the *Origin* and the *Descent,* Darwin claimed, and claimed truly, that a large number of naturalists admitted that species are the modified descendants of other species, and that this especially held good with the younger and rising naturalists. But he confesses that many of the older and honored chiefs in natural science unfortunately still opposed evolution in every form.

Here Darwin, with his usual fairness, sees the other side of the case, realizes the difficulties under which his opponents labored. He grants that the belief that animals so distinct as a monkey, an elephant, a humming bird, a snake, a frog, and a fish could all have sprung from the same parents will appear monstrous to those who have not attended to the recent progress of natural history, for

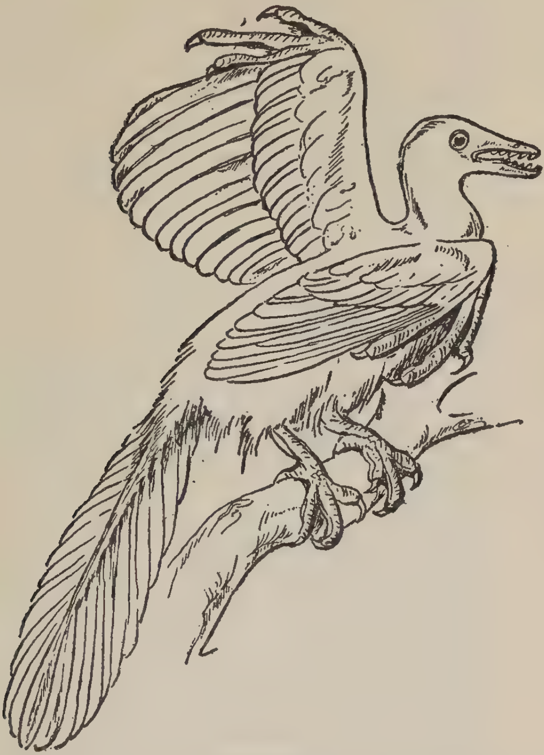


Courtesy of The New International Encyclopædia.

1. SKELETON OF DIPLODOCUS (Order Sauropoda).
(2-5, Restorations, after Osborn and Knight)
2. CERATOSAURUS (Order Theropoda).
3. STEGOSAURUS (Order Orthopoda).
4. HADROSAURUS (Suborder Ornithopoda).
5. TRICERATOPS (Order Ceratopsia).

DINOSAURS

this belief implies the former existence of links binding together all these forms, now so utterly unlike. Yet, he contends, every evolutionist will admit that the five great vertebrate classes, namely, mammals, birds, reptiles, amphibians, and fishes, are descended from some one proto-



ARCHEOPTERYX

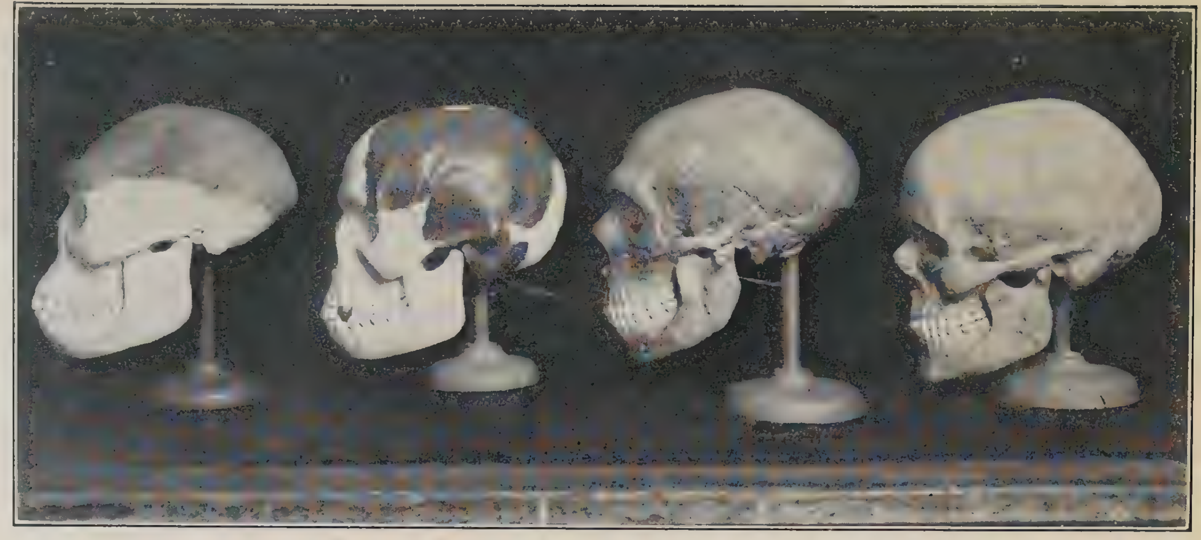
A "missing link" between reptile and bird. Observe the teeth in the jaws, the distinct finger and the elongated skeleton in the tail, with two feathers for each tail vertebra.

type, for they have much in common, especially during their embryonic state.

The embryologists had brought forward one line of evidence, the geologists were now bringing forward another. Professor Huxley had discovered and Mr. Cope of America confirmed the fact that the dinosaurians are in many important characters intermediate between certain reptiles and certain birds. The birds here referred to are the ostrich tribe and the archeopteryx, that strange fossil bird with lizard-like jaw, containing teeth, and a vertebrated tail. Also there are the ichthyosaurians, great sea lizards furnished with paddles and presenting affinities not only with fishes, but also with amphibians like frogs and toads.

Here is quite a collection of so-called missing links, a collection which has been largely added to in the fossil remains of the remote ancestors of the elephant, the camel, and the horse. The missing link for such animals as these is one thing, that for man another. Here the critics of the *Descent of Man* had one point in their favor. Except for the Neanderthal skull, homoidal or man-like creatures had not yet been discovered. The naturalist Linnæus in the century previous had portrayed a fanciful lot of "anthropomorpha" or creatures similar to men, but these were only crude copies of fictitious orang-outangs and chimpanzees, which he had heard about but never seen.

It remained for the present generation to bring to our knowledge authentic remains of the Java man of the East, of the Dawn or Piltdown man of England, of several additional specimens of the Neanderthal man, of the Crô-Magnon man of France, and the recently discovered



RECONSTRUCTED SKULLS OF PREHISTORIC MAN

Left to right: Pithecanthropus erectus, Piltdown, Neanderthal, Crô-Magnon.
Courtesy of the American Museum of Natural History.

Rhodesian skull from South Africa. It was the lack of evidence in his day that led Darwin to deplore the great gaps in the geological records, which even in the case of the shallow-water marine deposits have been estimated to preserve but little over one thousand of each hundred thousand creatures that once lived. As Huxley put it, "We have only the skimmings of the pot of life."

ANTHROPOMORPHA OF LINNÆUS

Darwin reasoned that man is descended from some lower form, notwithstanding the fact that connecting links had not hitherto been discovered. He repeats the argument that resemblances in several unimportant structures, in useless and rudimentary organs, or in embryological conditions are by far the most serviceable for classification, for they can hardly be due to adaptations within a late period, and thus they reveal the old lines of descent or of true affinity.

Now what is this descent or affinity? Darwin states that recently many of our best naturalists have placed man in the section of the primates. This means that man belongs to the first class of creatures, the mammals. Furthermore, the human body finds the top place in that scale which begins at the lower extreme with the lemurs and monkeys, and ends with man-like apes and man himself.

This raises the crucial question, the chief point of attack on the *Descent of Man.* Is man a creature separate from the rest of living creatures, a special creation with no relationship to his humbler brethren? At this juncture Darwin turns to his chief defender, and declares that the great anatomist Huxley concludes that man in all parts of his organization differs less from the higher apes than do those from the lower members of the same group. Consequently, "there is no justification for placing man in a distinct order."

This was the challenge, and the battle royal followed. In this connection we can recall the struggle that Copernicus had against the entrenched Ptolemaic system, and how Newton formulated the law of gravity, which at last explained the workings of our sun-centered system. As Huxley says: "In a dozen years the *Origin of Species* has worked as complete a revolution in biological science as the *Principles* of Newton did in astronomy." The reason given for this is that the doctrine of natural selection contained an essentially new creative thought. Or, as another scientist of the time expressed it, natural selection will assuredly become recognized as an established truth in science. It has the characteristic of all great natural truths, clarifying what was obscure, simplifying what was intricate, adding greatly to previous knowledge. Yet this scientist, who considered Darwin the greatest revolutionist in the natural history of his century, if not of all centuries, warned him that his views would lead him into trouble. The Darwinian chronology of animal life, if it includes man as one of the animals, "will shock the ideas of many men."

That was a true forecast and Darwin's *Letters* show it to be so. He writes to his old friend, the veteran geologist Lyell, that he thinks that he will be much execrated as an atheist. Huxley also tells him that considerable abuse and misrepresentation are in store for him, but that he must recollect that some of his friends are endowed with an amount of combativeness which may stand him in good stead and that he himself is sharpening up his claws and beak in readiness.

But Darwin was his own best defender. Nothing could be more calmly convincing than this final passage in the *Origin of Species:*

> It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of

conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.

§ 56. *Attack and Defense*

The *Letters* of Darwin show, as nothing else can, how fierce was the fight over natural selection, especially as regards the descent of man. One day there was praise; the next, blame. But at last the battle was won and a steady chorus of assent indicated that the new doctrine had carried the day. The *Origin of Species* itself had sold remarkably well for a profound book of science, while the second edition was sold out the first day to the trade and within six weeks was being asked after like a novel at the railway bookstalls. Across the water Professor Asa Gray of Harvard requested an American edition and promised that it should have fair play in the United States. His colleague, Professor Agassiz, had denounced the book, but that only gave it a fine advertisement. Gray explained this antagonism by saying that the theory of Agassiz regards the origin of species and their present general distribution over the world as equally primordial, equally supernatural; that of Darwin as equally derivative, equally natural. This has been explained as meaning that the old view held that when the world was made it was furnished with a complete set of animals and plants, whereas the transmutation view holds that all existing species are the result of the modification of preëxisting species by agencies similar to those which, at the present day, produce varieties and races.

In all this the so-called quarrel between the supernaturalists and naturalists crops up. But as Darwin once said to one of his clerical friends: "You are a theologian, I am a naturalist. The lines are separate. I endeavor to discover facts without considering what is said in the Book of Genesis. I do not attack Moses, and I think Moses can take care of himself." And at this very time, Charles Kingsley, author of *Westward Ho!*, declared that, in judging of Darwin's books, he would be free from two common superstitions:

> First, I have long since, from watching the crossing of domesticated animals and plants, learnt to disbelieve the dogma of the permanence of species. Second, I have gradually learnt to see that it is just as noble a conception of Deity, to believe that He created primal forms capable of self-development into all forms needful for the period and for the place, as to believe that He required a fresh act of intervention to supply the gaps which He Himself had made. I question whether the former be not the loftier thought.

In this connection Huxley said in support of the *Origin of Species:*

> I hardly know of a great physical truth, whose universal reception had not been preceded by an epoch in which most estimable persons had maintained that the phenomena investigated were directly dependent on the Divine Will, and that the attempt to investigate them was not only futile, but blasphemous. And there is a wonderful tenacity of life about this sort of opposition to physical science. Crushed and maimed in every battle, it yet seems never to be slain; and after a hundred defeats it is at this day as rampant, though happily not so mischievous, as in the time of Galileo. . . . Surely it is the duty of the public to discourage anything of this kind, to discredit these foolish meddlers who think they

do the Almighty a service by preventing a thorough study of His works.

Nevertheless some of the scientists could not see their way to accepting the new views. The veteran geologist Lyell at last came over to the evolutionists but before his conversion Darwin had held a mild theological controversy with him on the subject of natural selection. So Darwin puts his question and his own answer in this way:

> Do you consider then that the successive variations in the size of the crop of the Pouter Pigeon, which man has accumulated to please his caprice, has been due to "the creative and sustaining powers of Brahma"? In the sense that an omnipotent and omniscient Deity must order and know everything, this must be admitted; yet, in honest truth, I can hardly admit it. It seems preposterous that a maker of a universe should care about the crop of a pigeon solely to please man's silly fancies.

In view of such difficulties Lyell finally feels bound to confess his evolutionary faith, and describing a later meeting of the British Association wrote to Darwin that "You and your theory of evolution may be fairly said to have had an ovation." But this was fifteen years after the appearance of the *Origin of Species*. At an earlier meeting of the Association, only a year after the book appeared, there occurred the famous pitched battle in the campaign for natural selection. Darwin had already hinted that man, though the highest of the animals, was nevertheless related to creatures beneath him. Now there was a discussion as to the affinities between the brain of man and that of the gorilla. One speaker asserted that these differences were greater than the resemblances.

Huxley denied this. Hereupon uprose the Bishop of Oxford, and in the course of an eloquent but empty speech turned to Huxley and asked him whether he was "related by his grandfather's or grandmother's side to an ape." To this Huxley gave a crushing rejoinder: "I asserted, and I repeat, that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor whom I should feel shame in recalling, it would be a *man,* a man of restless and versatile intellect, who, not content with an equivocal success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by an aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions, and skilled appeals to religious prejudice."

Darwin referred to this as the battle royal at Oxford. But as for himself he was never personal as was Huxley in his retorts, and always answered with a "noble calmness." For instance, when another prominent cleric, Dr. Pusey, preached against the *Origin of Species,* he wrote to a friend:

> Dr. Pusey's attack will be as powerless to retard by a day the belief in evolution, as were the virulent attacks made by divines fifty years ago against geology, and the still older ones of the Catholic Church against Galileo, for the public is wise enough always to follow scientific men when they agree on any subject; and now there is almost complete unanimity amongst biologists about evolution, though there is considerable difference as to the means, such as how far natural selection has acted, and how far external conditions, or whether there exists some mysterious innate tendency to perfectibility.

This was written thirteen years after the *Origin of Species,* yet even a single year after its appearance Darwin declared that he was astonished and rejoiced at the progress which the subject had made, and drew up for a friend a list of some fifteen prominent scientists who accepted his doctrine wholly or in part. This list included geologists, zoologists, physiologists, and botanists, and among the last was put Asa Gray. To this American advocate Darwin wrote that he was more than any one else the thorough master of the subject, and it was Gray whom Darwin described to another as fighting like a hero in defense of evolution, especially against the attacks of Agassiz. The latter upheld a curious view that the forms of life which one after another tenanted the globe were incarnations of the successive thoughts of the Deity, and that He wiped out one set of these embodiments by an appalling catastrophe as soon as His ideas took more advanced shape. But, as Huxley added, this was a scheme of nature which did not appeal to him, being modeled on the likeness of a succession of rubbers of whist, at the end of each of which the players upset the table and called for a new pack of cards.

This view would hardly hold, for, as Lyell points out, there is a great principle at work in the universe, namely, that the past must be explained by the present, unless good cause be shown to the contrary. This is what is called the uniformitarian view which so smoothed the way for Darwin. It meant that the same causes work always the same way, that what is happening now happened long ago. Hence it calls for no special creations and no terrible catastrophes, earthquakes, floods and the like. Nor does it require that the forms of one geological age be wiped out and replaced by entirely new forms. Instead it presents a steady change, a spontaneous growth, one species evolving from another and all going to form the great tree of life.

This was the new view which was destined to win. But meanwhile the upholders of the old view of special creation and catastrophe would not acknowledge defeat. Agassiz raised the strongest objections to Darwinism on this side of the water and in 1860 attacked the *Origin of Species* both at the meeting of the American Academy of Sciences and of the Natural History Society of Boston, but in the same year Darwin was elected a correspondent of the Academy of Natural Sciences at Philadelphia. In all this Asa Gray played a great part. He believed that proofs of special creation were not attainable, but that derivation or transmutation of species might be. Like a true scientist he was cautious at first, but the evidence presented by the Englishman Darwin was so strong that he could not but give his studies the name of *Darwiniana*. Still he allows that there are certain difficulties in the way of the acceptance of the new theory. The first is the imperfection of the geological remains. All but the last volume of fossil lithography is out of print, and of its pages only local glimpses have been obtained. Another difficulty is that of the "missing link." Wide is the gap between the highest quadrumana, or four-handed creatures, and man, and where is there the slightest evidence of a common progenitor?

Here are defects in evolution which Darwin himself had acknowledged and for which his chief American advocate had no answer. These were real gaps in the road of progress and it is significant that two other Americans furnished material to fill them in. One was Professor Marsh of Yale University, who offered the first complete fossil pedigree of the horse, and the other Professor Cope of the University of Pennsylvania, who made certain suggestions as to man's ancestors which have since been verified.

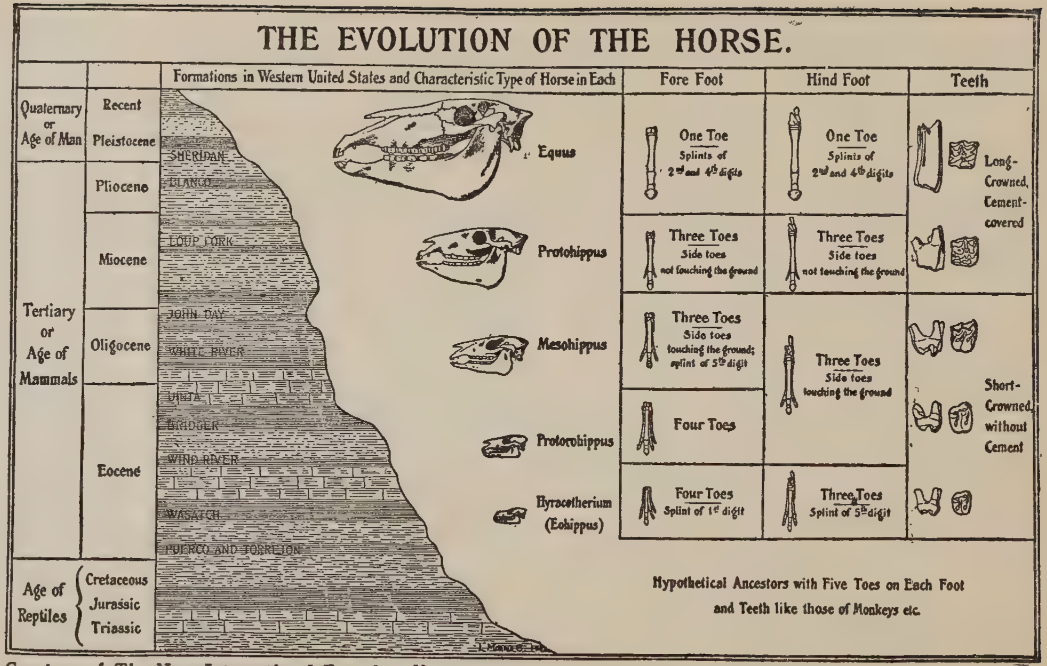
§ 57. *The Advance of Evolution*

When Huxley came to America to deliver his famous New York addresses, he first visited the Peabody Museum at New Haven. There Professor Marsh had at last gathered materials, largely from the Bad Lands of the West, that proved that at least one animal, the horse, had an unbroken ancestry from the remotest times. Darwin had deplored the missing chapters in the book of geology. But as Huxley said, now in 1880, natural selection had at last reached its "coming of age" and in the twenty-one years which had elapsed since the publication of the *Origin of Species,* much new evidence had accumulated. Here there are two telling instances. One shows how the gulf between two such apparently distinct groups as birds and reptiles has been bridged over by ancient fossils intermediate in form. The other shows the lineal descent of the specialized horse from the more general type of quadruped. The reptile-like birds, whose remains were found in the ancient Connecticut River Valley, exhibited teeth and a long vertebrated tail. These extinct toothed birds of North America were certainly remarkable, for they removed from the realm of conjecture to that of fact Darwin's difficulty as to many animal forms of life having been utterly lost, forms through which the early progenitors of birds were formerly connected with the early progenitors of the other vertebrate classes.

More remarkable was a series of "transitional forms" in the geological history of the horse. The farthest back of these, says Huxley, was a creature with four toes on the front limb and three on the hind limb. But this was only part of the story. The pedigree was not complete, so Huxley indulged in a prophecy that when the still lower Eocene deposits and those which belong to the Cretaceous epoch have yielded up their remains of ancestral and equine animals we shall find five-toed animals, in which, if the doctrine of evolution is well founded, the whole series must have taken its origin. This prophecy was soon fulfilled. Within two months Professor Marsh had discovered a new genus of equine mammals which he called Eohippus, from the lowest Eocene deposits of the West, which corresponded very nearly to Huxley's description.

Such were the new proofs from the New World. Darwin was naturally delighted with them. As he wrote to Professor Marsh, the latter's work on the many fossil animals of North America had afforded the best support to the theory of evolution which had appeared in the previous twenty years.

But a second great gap remained to be filled up and this was not accomplished in Darwin's lifetime. In the *Descent of Man* he had stated that there could be hardly any doubt that man was an offshoot of Old World simian stock. Darwin mentions the Neanderthal skull as being of very high antiquity, but that skull turned out later to be only one of a longer series. Meanwhile it has remained for this generation to discover three and perhaps four transitional forms, which came before the Neanderthal man type. These are what is known as the Java man, the Heidelberg man, ~~the Piltdown man,~~ and perhaps the


THE EVOLUTION OF THE HORSE.
Formations in Western United States and Characteristic Type of Horse in Each
Fore Foot
Hind Foot
Teeth
Quaternary or Age of Man
Recent
Pleistocene
Pliocene
Tertiary or Age of Mammals
Miocene
Oligocene
Eocene
Age of Reptiles
Cretaceous
Jurassic
Triassic
SHERIDAN
BLANCO
LOUP FORK
JOHN DAY
WHITE RIVER
UINTA
BRIDGER
WIND RIVER
WASATCH
PUERCO AND TORREJON
Equus
Protohippus
Mesohippus
Protorohippus
Hyracotherium (Eohippus)
One Toe Splints of 2nd and 4th digits
Three Toes Side toes not touching the ground
Three Toes Side toes touching the ground; splint of 5th digit
Four Toes
Four Toes Splint of 1st digit
One Toe Splints of 2nd and 4th digits
Three Toes Side toes not touching the ground
Three Toes Side toes touching the ground
Three Toes Splint of 5th digit
Long-Crowned, Cement-covered
Short-Crowned, without Cement
Hypothetical Ancestors with Five Toes on Each Foot and Teeth like those of Monkeys etc.

Courtesy of The New International Encyclopædia.

TRANSITIONAL FORMS IN THE GEOLOGICAL HISTORY OF THE HORSE

Rhodesian man. However the latest published description of the remains of the South African skull and skeleton have led some to think that it is later than the Neanderthal type. Its head was evidently well balanced on the neck and this, together with the straight shin and the character of the ends of the thigh bones, imply a fully erect posture.

Several of these Old World skulls have been restored and models of them are to be found in the American Museum of Natural History in New York. But as these skulls of ancient types of men are not stages in a single evolutionary type line, but probably represent four divergent lines, the problem is to find a common center from which they may have radiated. In order to solve this ancient problem of human origin the Museum is at present conducting a systematic exploration in Northern Asia.

This all goes back to Darwin's conjecture as to man originating from Old World simian stock. There are, of course, certain fossil remains of the new world, such as the Calaveras skull of California, the Nebraska man, the Lansing man, and those of Vero, Florida, and Dallas, Texas, but none of these, it is stated, meets the requirements of the anthropologist, for none shows characters which are not possessed by the modern American Indian. However from the Old World skulls the antiquity of man is pushed back amazingly. The Java man is put before the first glacial time, and as the modern type, like the Crô-Magnon *homo sapiens,* the reasoning man, is placed after the fourth glacial time, man's authentic ancestry is to be put in terms of hundreds of thousands of years. This leads, then, to this summary of the recorded changes in prehistoric man:

Increasing cranial capacity, with perfection of the brain, especially in that portion which is concerned with the higher intellectual faculties and with speech.

Change in skull conformation, heightening forehead, and lessening brow ridges.

Reduction of jaw power and of dental arch, which results in the formation of the chin prominence.

Changes in the teeth, such as reduction of the canines.

Stature increasing and becoming more erect, although the earliest known type, the Java man, was fully upright, pointing to great antiquity for this characteristic.

Still the problem is not yet solved. There remain gaps to be filled. These call for further steps in the advance of evolution. But, as a recent authority declares, the explorations in Asia now being carried forward will, it is hoped, yield additional light on the problem of human origin, for all of our evidence points to central Asia as the birthplace of mankind, and to the Miocene, one million to two million years ago, as the time of his origin.

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